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Monterey, California



THESIS

COST ESTIMATION AND PRODUCTIVITY IMPROVEMENT
WITHIN THE DEPOT MAINTENANCE ACTIVITY

by

Robert Dean Larson

March 1983

Thesis Advisor:

James G. Taylor

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T208018

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Cost Estimation and Productivity Improvement Within the Depot Maintenance Activity		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis March 1983
7. AUTHOR(s) Robert Dean Larson		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE March 1983
		13. NUMBER OF PAGES 77
		15. SECURITY CLASS. (of this report)
		13a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Equipment Readiness Cost Estimation Productivity Improvement Depot Maintenance Activity		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Equipment readiness is an essential component in maintaining the Marine Corps as this country's "Force in Readiness". In today's environment of austere funding, improved productivity and reliable budgeting processes are critical elements within the Depot Maintenance Activities. The optimal utilization of available resources is paramount to the enhancement of Fleet Marine Forces equipment readiness. This thesis uses the quantitative techniques of multiple linear regression, survey analysis and linear programming in an effort		

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Cost Estimation and Productivity Improvement Within
the Depot Maintenance Activity

by

Robert Dean Larson
Captain, United States Marine Corps
B.S., United States Naval Academy, 1974

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March 1983

ABSTRACT

Equipment readiness is an essential component in maintaining the Marine Corps as this country's "Force in Readiness". In today's environment of austere funding, improved productivity and reliable budgeting processes are critical elements within the Depot Maintenance Activities. The optimal utilization of available resources is paramount to the enhancement of Fleet Marine Forces equipment readiness. This thesis uses the quantitative techniques of multiple linear regression, survey analysis and linear programming in an effort to model an automated management system for the maximum allocation of resources at the two existing Marine Corps depots.

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I. INTRODUCTION

The first duty of any military organization is the accomplishment of its mission. Today's peacetime mission for the Marine Corps is readiness with efficient resource utilization and reliable budgeting information serving critical roles. In the current environment of austere funding, it is of primary importance that budget planners be provided with accurate, up-to-date information. Accordingly, it is of equal importance to combine these dollars and the available labor workforce in their optimal mix to obtain the maximum output possible. The mathematical techniques needed to achieve this optimization are available within the academician's world, and can yield highly accurate results to questions that could only be answered previously by 'best guesses.' It is time to bridge the communication gap between the theoretical and practical worlds within the logistics field.

Historical information forms the basis of most of the mathematical techniques that are available and therefore it is of critical importance. Fortunately, logistics planners within the Marine Corps identified the need for the compilation and storage of this historical data. The reorganization of logistic support structures to allow for this collection and storage of data is well underway. The new structures incorporate the lessons of recent combat with the logistical techniques that are currently practiced by both the government and civilian industries today. Changes in organizational structure occurred in parallel with the changes in the logistics systems. As these systems evolved, planned

reorganizations were implemented, taking advantage of the new systems such as the Marine Corps Integrated Maintenance Management System (MIMMS), the Supported Activities Supply System (SASSY) and the Marine Corps Readiness Evaluation System (MARES).

Although these systems were not developed for the sole purpose of providing historical data, it is the time now to take advantage of this by-product and put it to its fullest use. An automated management system could be developed that would lead to greater system efficiency and effectiveness through better planning. All of this is available once our abundance of historical data is put to its maximum use. One such management system could be installed at the Depot Maintenance Activities (DMA). Quantitative forecasting can predict numbers of carcass returns and resource allocation models can outperform "seat of the pants" methods for the construction of the Master Work Schedule. Once the results are calculated, they can further be utilized to provide cost estimates for the operations of the DMA for submission to the Five Year Defense Plan.

II. CURRENT ORGANIZATION

The following organizational background information is given in an effort to identify the contextual setting for the problem statement that is contained in the following section.

A. GROUND EQUIPMENT MAINTENANCE ENVIRONMENT

The FMF has been undergoing a series of evolutionary changes in its logistic support structure and its supporting systems during the past five years. Much of this effort concentrated on corrections to deficiencies identified during the logistic rigor of the Vietnam War. Four areas of logistic management that have changed in the FMF are: the organizational structures, supply, maintenance management and the readiness reporting systems. [Ref. 1]

Organizational structures have undergone a change designed to shape the Tables of Organization (T/O's) more around the combat, combat support and combat service support structures as described in Ref. 2. Figure 1 outlines the common structures that have evolved. The consolidation of logistic support into modularized service support elements is characteristic of the reorganizational emphasis on equipment readiness support.

The organizational emphasis on the centralization of logistic effort is supported by the use of automated data systems for the processing of supply, maintenance and readiness evaluation data. The centralized logistic units of the FMF are more capable of coordinating these multiple information systems than were the decentralized structures.

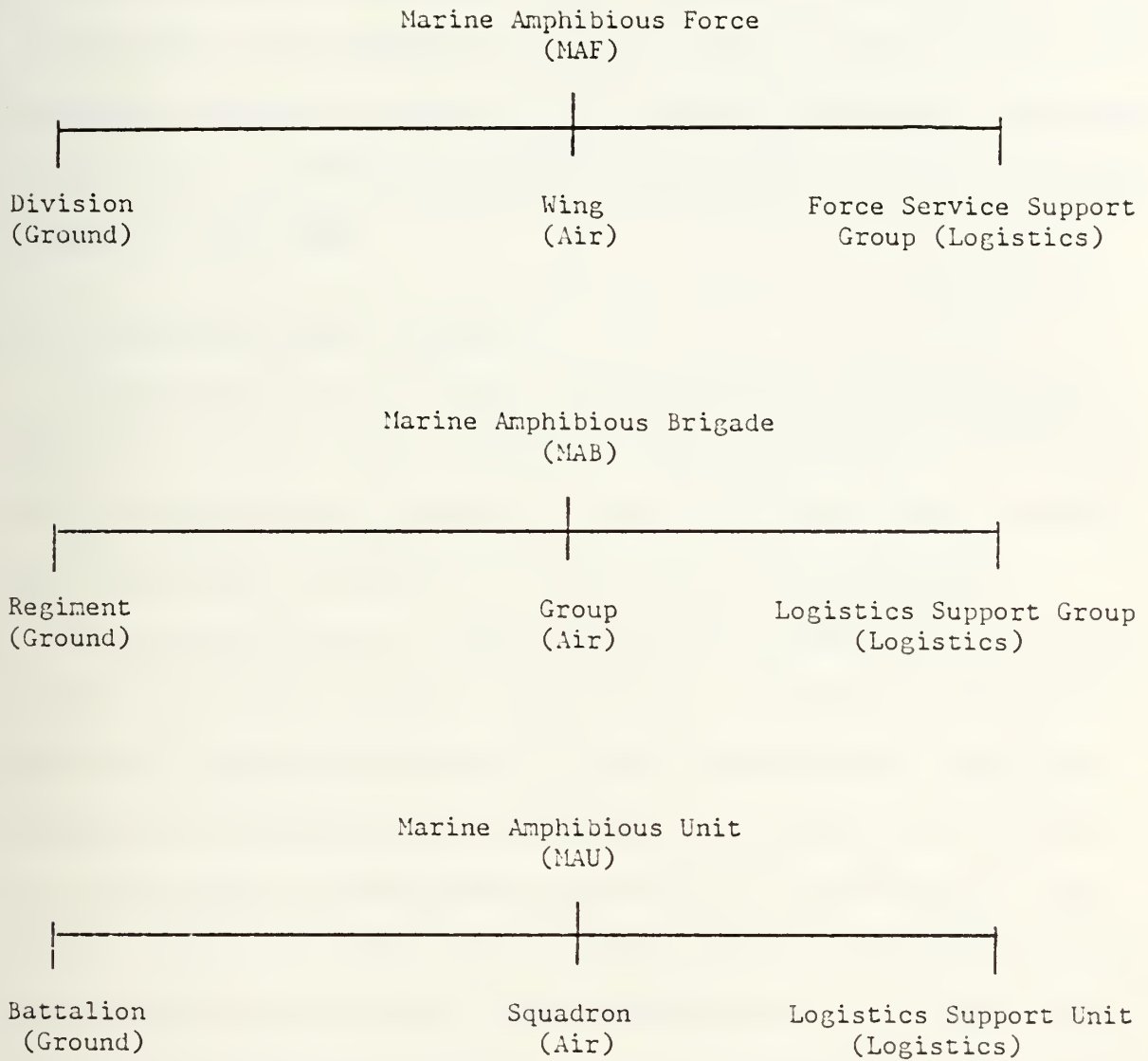


Figure 1. Three Basic Organizational Structures for the FMF

Maintenance management information has been centralized within the logistics units. The logistic units depicted in Figure 1 correlate and report information to using units, major commands and Headquarters level organizations. The information consists of supply, maintenance operations, equipment readiness and historical data relating to equipment maintenance. Figure 2 shows the MAF structure and relationships involved in maintenance management under MIMMS.

B. MAINTENANCE SUPPORT STRUCTURE

Maintenance consists of those actions required to retain or restore equipment to a serviceable condition. Commonly included in this description of maintenance are inspection, testing, servicing, repair, replacement, rebuilding, serviceability classifications and reclamation.

Maintenance services in the Marine Corps are governed by the logistic capabilities of the individual organizations. The Tables of Organization define for each organization their logistic capabilities. Three major categories of maintenance are divided into five echelons of maintenance to further define the maintenance capabilities of organizations. The echelons define the time, tools, equipment, parts and personnel available, authorized and required for a maintenance function. The official description of the maintenance structure in Ref. 3 is summarized in the following paragraphs.

1. Organizational Maintenance Level

Maintenance performed, authorized and within the responsibility of an organization on its own equipment is categorized as organizational. Two major types of maintenance actions performed at the organizational and field maintenance levels are preventive and corrective maintenance.

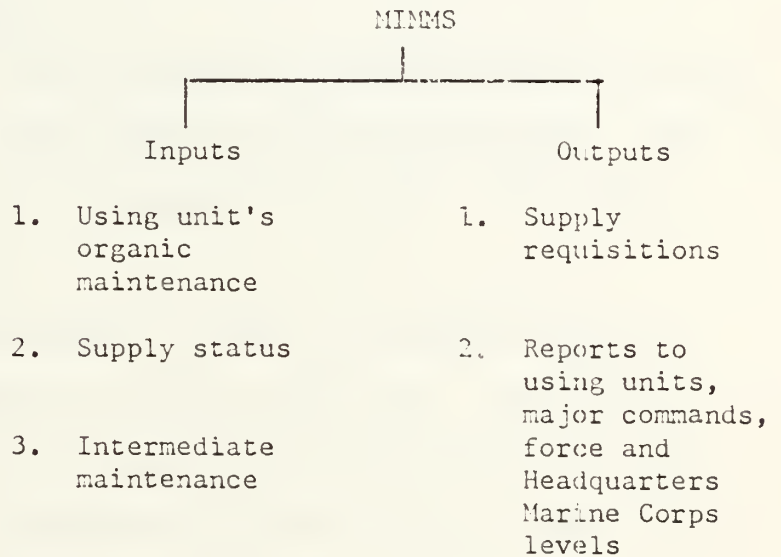
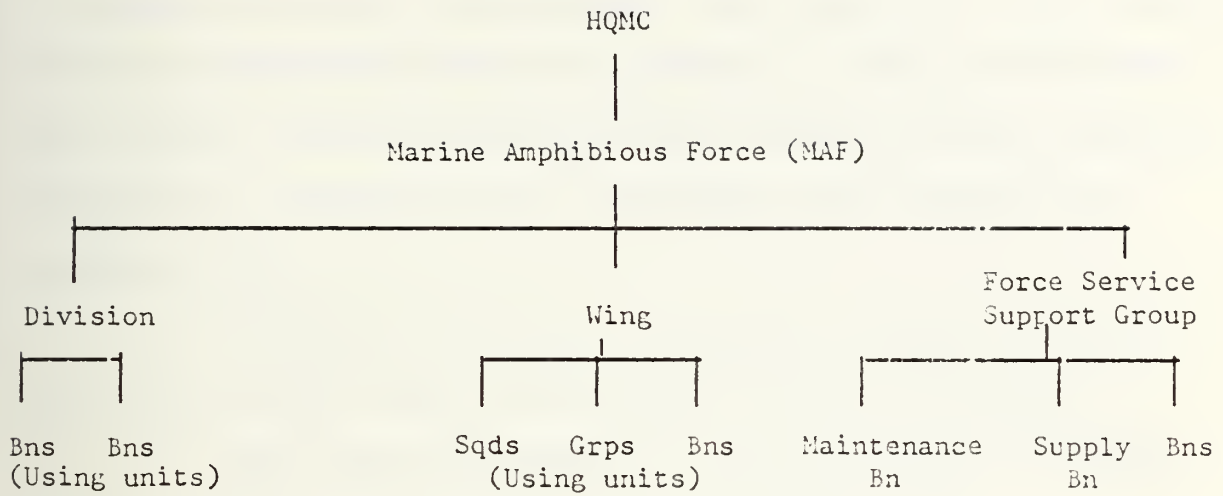


Figure 2. MIMMS Structure and Overview within an MAF

Preventive Maintenance (PM) is the effort to prevent or detect incipient equipment failures. Early detection is intended to reduce the downtime of equipment and improve its performance. Requirements for PM are focused at the first and second echelons of maintenance. Corrective Maintenance (CM) consists of those actions which repair, replace or adjust assemblies, subassemblies or defective parts. Two echelons within organizational maintenance are:

- a. First Echelon Maintenance - preventive care and cleaning, lubrication and minor testing repair done by the user or operator.
- b. Second Echelon Maintenance - actions performed by a trained member provided for that purpose in the using organization.

2. Field Maintenance Level

Field Maintenance is that performed and authorized by specifically designated organizations in direct support of using organizations. [Ref. 2] Repaired items from this level are returned to the user. Two echelons within field maintenance are:

- a. Third Echelon Maintenance - actions performed by specially trained units in direct support to multiple using units. Select individual using units may, due to the peculiar and limited nature of some equipment, be authorized to perform their own third echelon repair. This echelon consists of part or module-type replacement.

- b. Fourth Echelon Maintenance - actions performed by specially trained personnel beyond the supported using unit's capabilities. The functions performed provide for repair of assemblies and subassemblies.

3. Depot Maintenance Level

Depot maintenance is the fifth echelon and is the repair of materiel that requires major overhaul or rebuild. [Ref. 3] Equipment

repaired is returned to stock rather than to the user. It is within this level that this thesis will attempt to use the mathematical and statistical tools available to help provide the Marine Corps budget planner with the information crucial to making reliable cost estimations within the Depot Maintenance Activities for the upcoming and four subsequent budget years.

C. DEPOT MAINTENANCE STRUCTURE

The Marine Corps operates two Depot Maintenance Activities (DMA's). These activities are located at Marine Corps Logistics Base, Albany, Georgia and at Marine Corps Logistics Base, Barstow, California. The DMA's accomplish major repair and overhaul of all types of Marine Corps tactical, combat and support equipment. They are responsible for the timely collection and reporting of data to Headquarters Marine Corps and the Inventory Control Point (ICP) in the format and accuracy required to support management functions at those levels. [Ref. 4]

1. Organizational Structure of the Depot Maintenance Activity

The standard organizational structure for the DMA is shown in Figure 3. The DMA contains within its organization all essential elements for management of production, costs and quality. It is responsible for the development of detailed schedules and the development of local management techniques to ensure execution of the program requirements levied by Headquarters Marine Corps.

The Commandant of the Marine Corps Master Work Program (CMC MWP), the ICP Depot Repairable Program and the Supply Center Support Program constitute the annual Master Work Schedule (MWS) as illustrated in Figure 4.

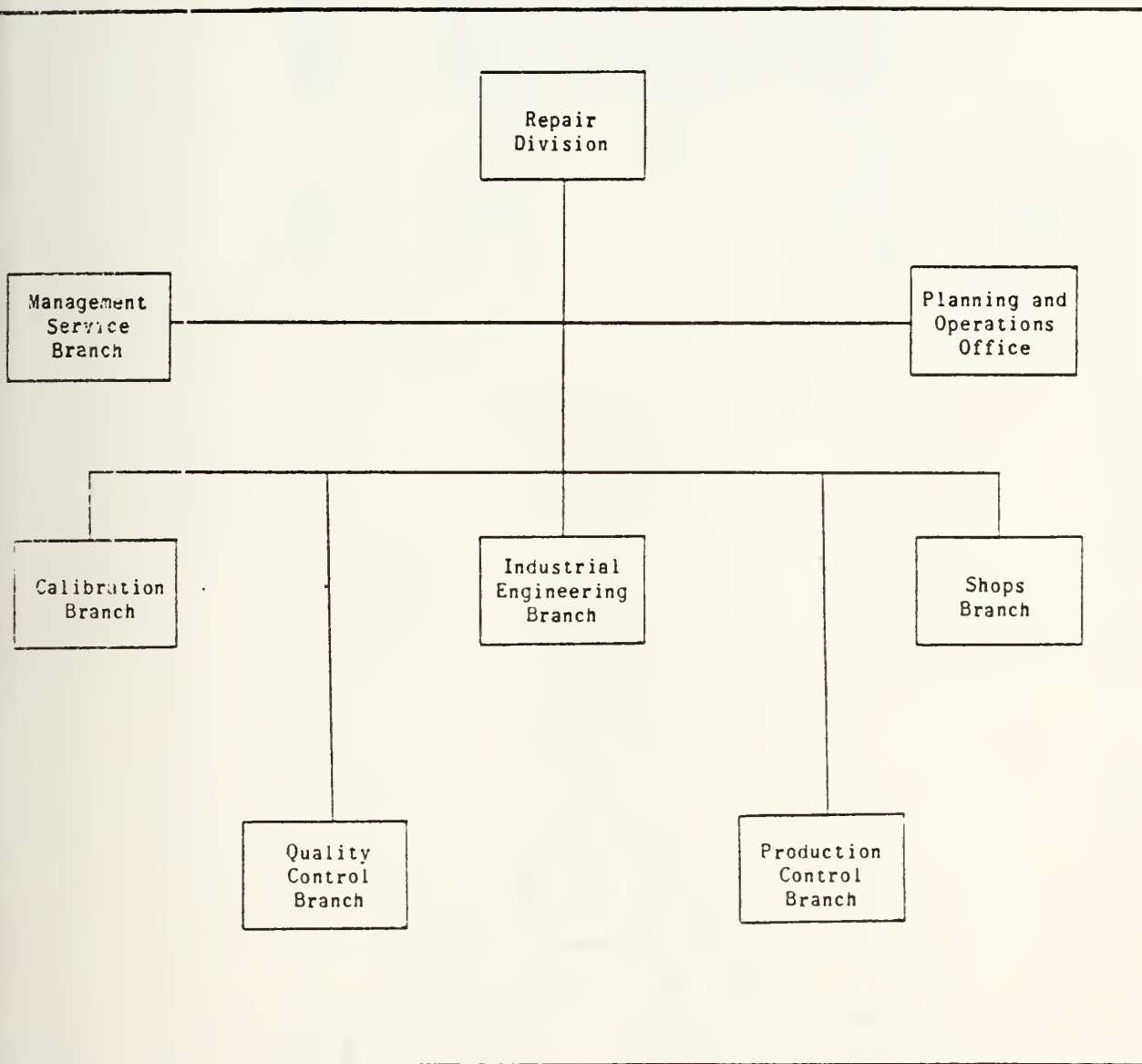


Figure 3. Standard Organizational Structure for a DMA

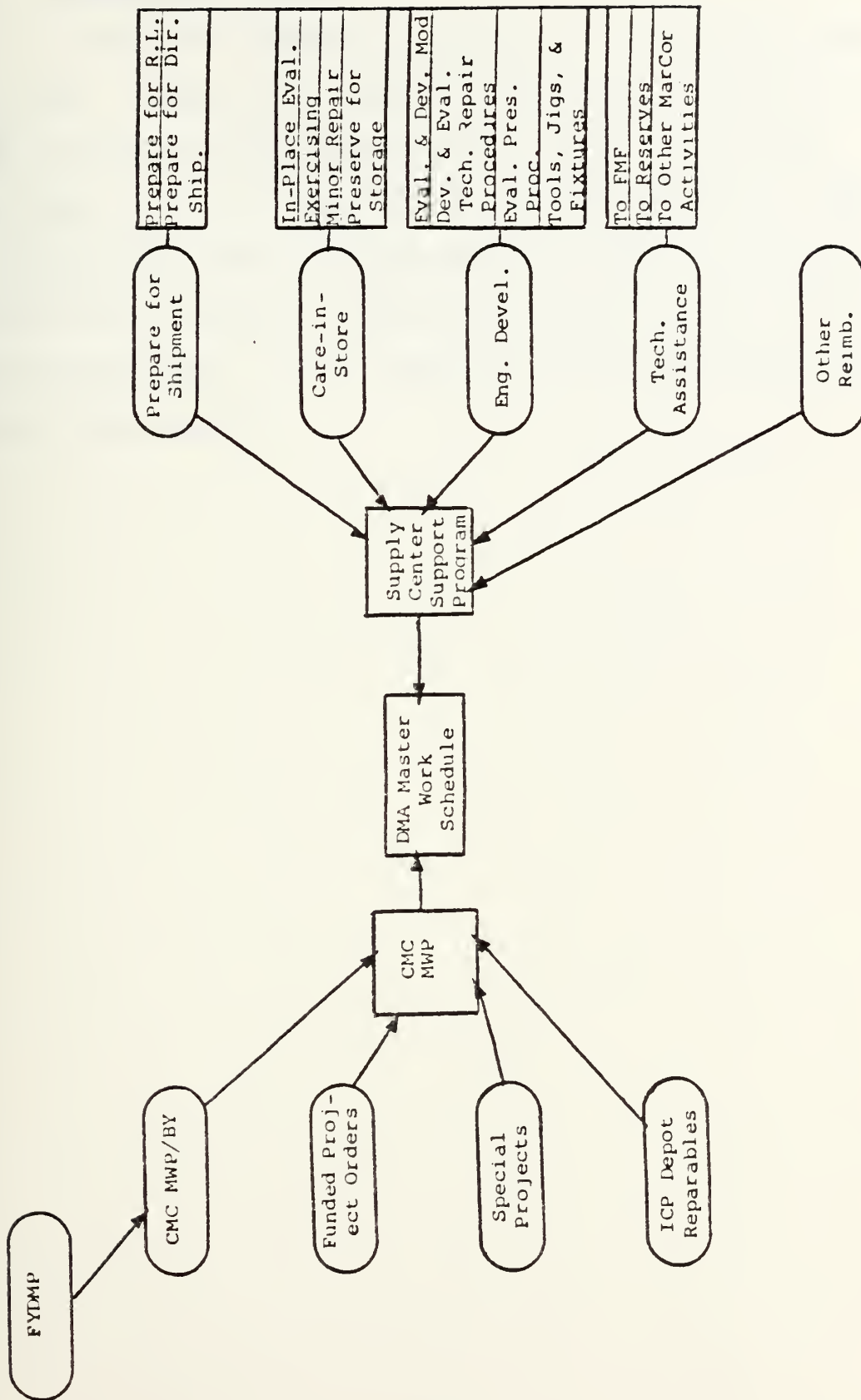


Figure 4. Master Work Schedule Preparation Chart

2. The Master Work Schedule

The Master Work Schedule is maintained in an up-to-date status at all times. Changes to the line item and quantities contained in the CMC MWP are received from Headquarters Marine Corps as requirement changes occur. Line item changes are estimated and scheduled by induction and completion dates as the changes are received. The status of allotted funds in relation to schedule requirements are maintained as changes are estimated. A formal submission of the revised Master Work Schedule is made quarterly.

III. PROBLEM

A. STATEMENT OF THE PROBLEM

Reference 4 tasks the Depot Maintenance Activities at Barstow and Albany with providing cost estimates for the Master Work Schedule within the Five Year Defense Plan. These estimates are utilized by Headquarters Marine Corps in the preparation of the apportionment budget.

Currently, the Interim Material Management Programming Model (IMMPM) and the Stratification subsystem are used to identify the total Principal End Item (PEI) and Secondary Depot Repairable (SDR) requirements which are then used as the basis for rebuild computations. These quantities are then priced out against an average cost to rebuild and a budget estimate is provided. The fallacy behind this thought process is the simple fact that planners are trying to use the output of the requirements computation (MMPM and Strat) as input to the Master Work Schedule when neither of these systems consider the output capacity of the DMA. Instead, the output of the Master Work Schedule should be used as input to the requirements computation. In addition, the model used within the IMMPM assumes unlimited funding and a continuous supply of carcass returns as do most models of this nature. Unfortunately, these assumptions are not valid for the Marine Corps due to its limited size and budget. It is quite obvious that the IMMPM was devised to calculate PEI and SDR requirements based on such things as usage, carcass return rate, depot level maintenance survival rates and budget constraints, and that it was then in turn forced upon the Master Work Schedule cost estimators. Once again, it is the story of trying to make automated

systems perform in areas they were not designed for and are incapable of handling. The problem statement is: Construct a set of programs that will yield the optimal mix of PEI's and SDR's to be repaired at the two Depot Maintenance Activities and calculate the associated cost estimation for the budget year and four subsequent years.

B. CONSTRAINTS

Due to the limited number of programmer assets available within the Marine Corps, it is believed that any methods identified to improve cost estimating techniques should meet the following requirements: First, the technology must exist and not create any unusual financial burdens on the user. Next, existing data bases and supporting programs must not be altered beyond simple modular replacement. Finally, changes to implement the methods must not increase the workload of the user or the initial input source.

C. METHODOLOGY

The Marine Corps Integrated Maintenance Management System currently tracks the life cycle maintenance records for all serialized Principal End Items and Secondary Depot Repairables. This historical data base can be used to calculate the regression coefficients for any number of factors relating to overhaul date. The regression equation will yield the approximate date when each serialized item would require depot level rebuild. These estimates can then be aggregated and sorted by end item and fiscal year.

Two look-up tables must then be constructed. The first will contain the different skill levels at each Depot Maintenance Activity and

the number of people within each level and the second will contain the times utilized in completing industrial work measurement standards. Finally, a method must be established to obtain the priorities of maintenance for each PEI and SDR. These priorities will serve as the objective function coefficients for the linear program that will be utilized to achieve the optimal resource allocation. These vectors will then be arranged into a tableau and input into the aforementioned linear program. This will yield the optimal mix of PEI's and SDR's that should be rebuilt at each DMA during the Five Year Maintenance Defense Plan. These estimated numbers of PEI's and SDR's can then be priced out against the average cost to repair each individual item giving the required budget estimations.

IV. BUDGETING PROCESS

The purpose of the budget process is to allocate scarce resources among competing public demands in order to seek attainment of objectives. Budgeting is geared to a cycle which allows the system to absorb and respond to new information. The cycle has four main phases: (1) executive formulation; (2) congressional enactment; (3) budget execution; and (4) audit. Each of these phases interrelates and overlaps the others. Figure 5 depicts the first three phases of the budget process and divides the first phase, executive formulation, into the planning, programming and budgeting stages of DoD's formulation process. As shown, there are always three different fiscal year budgets active. [Ref. 5]

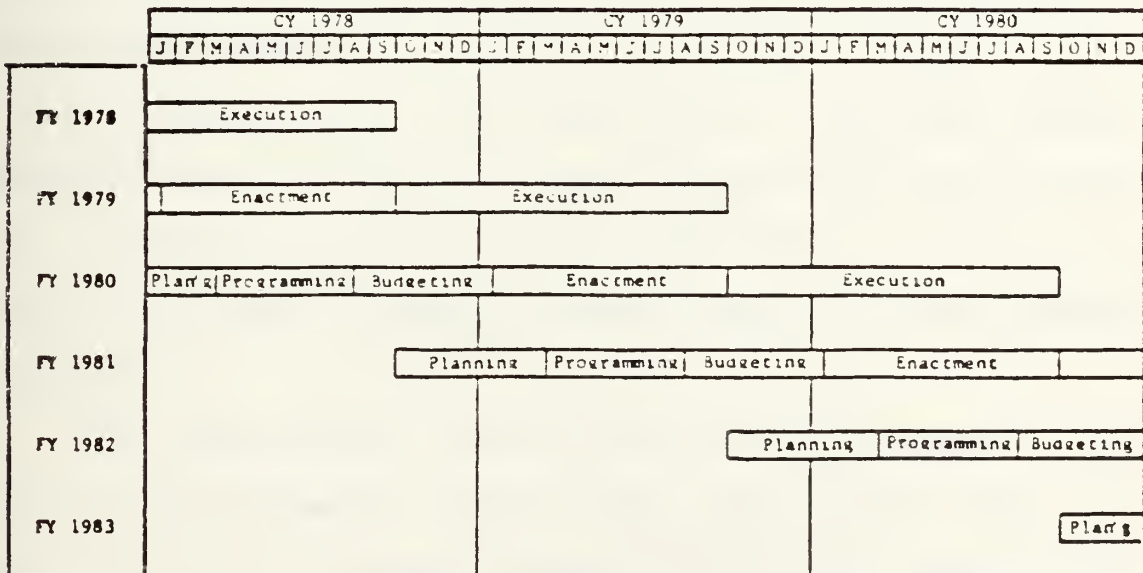


Figure 5. Three Phases of Budget Process

A. APPROPRIATION AND PROGRAM BUDGETS

The DoD budget is divided into two parts. First in terms of input of resources, described in the appropriation format, and secondly, in terms of output, described in the program format.

1. Appropriation Format

An appropriation is an authorization, by Act of Congress, to incur obligations for specific purposes and make payment therefore out of the Treasury. Appropriations can be categorized in at least three different ways; as to purpose (either expense or investment); as to duration (annual or multiple years); and as to the level of funding (either incrementally or fully funded).

2. Program Format

Traditional budgeting is concerned with the input of resources while program budgeting is concerned with the output of programs. The program budget sets forth what accomplishments can be expected from the resources made available.

The building block of the Program Budget is the Program Element. A Program Element is a grouping of forces, manpower and costs associated with an organization, a group of similar organizations, a function or a project. Each Program Element will normally consist of forces, manpower and costs.

The Program Element concept allows the operating manager to participate in the programming decision process since both the inputs and outputs are stated and measured in Program Element terms. Similar program elements are aggregated, or grouped, into major programs. The ten major programs (output) and their support appropriations (input) comprise

the Five Year Defense Program (FYDP). They are as follows:

- Program 1 - Strategic Forces
- Program 2 - General Purpose Forces
- Program 3 - Intelligence and Communications
- Program 4 - Airlift and Sealift
- Program 5 - Guard and Reserve Forces
- Program 6 - Research and Development
- Program 7 - Central Supply and Maintenance
- Program 8 - Training Medical and Other General Personnel Activities
- Program 9 - Administrative and Associated Activities
- Program 0 - Support of Other Nations

These ten programs are conceptualized in Figure 6.

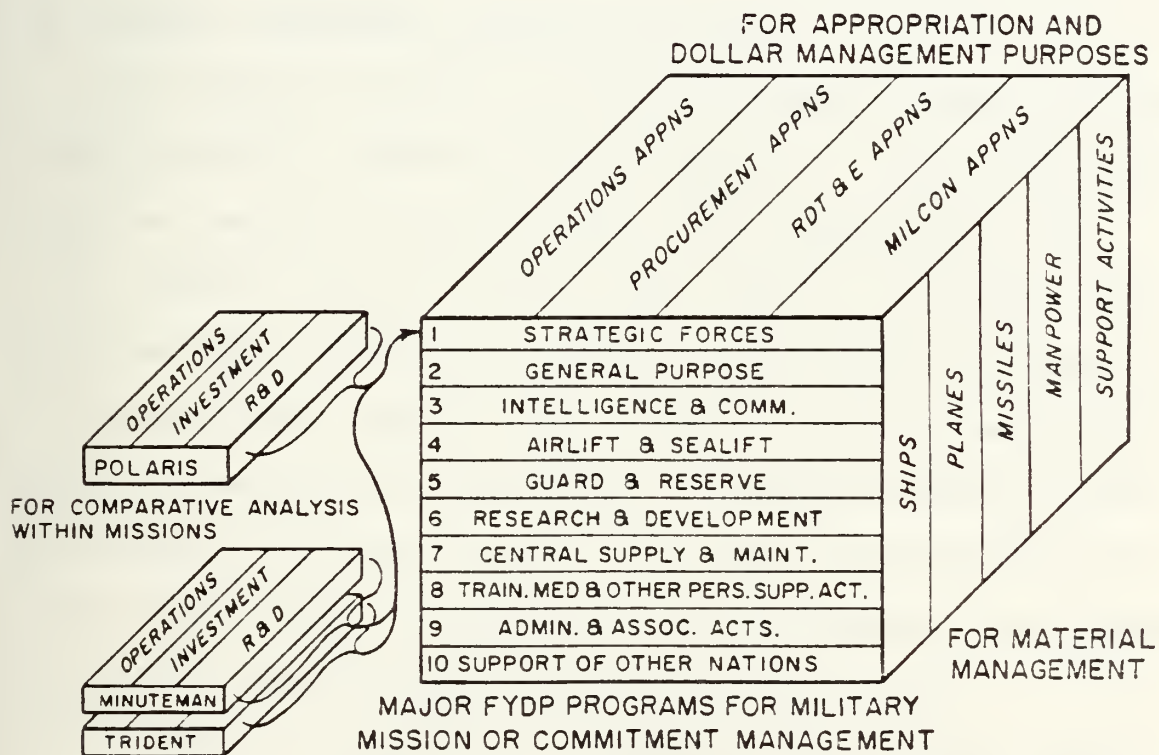


Figure 6. Concept of DOD Programming System

The Five Year Defense Program is the publication that records, summarizes and displays the decisions that have been approved by the SECDEF as constituting the DoD's program. It is a management tool that keeps management informed of what has been accomplished in the past and what is to be accomplished in the future to support the national strategy decisions. The FYDP is updated at least three times a year; in October, after Congress has enacted new fiscal year Appropriations Bills, in January based on the President's submittal of his FY+1 Budget and in May based on the Program Objective Memorandum (POM).

B. PLANNING, PROGRAMMING AND BUDGETING SYSTEM

The Planning, Programming and Budgeting System is simply a decision making process for allocating defense resources. It takes almost two years and involves four major players at the Washington D.C. level (i.e., OMB, OSD, JCS, the Services) who, through an iterative process move from broad planning considerations, to more definitive program objectives to finally specific budget estimates which price out the programs. In the simplest of terms, PPBS is a system designed to assist the Secretary of Defense in making choices about the allocation of resources among a number of competing or possible programs and alternatives to accomplish specific objectives in our national defense.

The Planning, Programming, and Budgeting System contrasts with the traditional budgeting process which preceded it in two significant ways. First, PPBS tends to focus less on the existing base and annual incremental improvements to it. Instead, its focus is more on objectives and purposes, and the long-term alternative means for achieving them. As a result of this emphasis, planning has been elevated to a level on par

with budgetary management and control. Secondly, the system brings together planning and budgeting by means of programming, a process which essentially defines a procedure for distributing available resources equitably among the many competing or possible programs.

The PPBS process is depicted in Figure 7 and is described as follows:

1. Planning

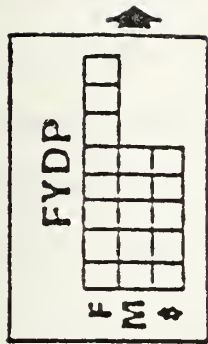
Planning, the first phase of the PPBS starts with the assessment of the threat to the security of the United States and, when combined with national policy, culminates in the development of force objectives to assure the security of the United States. In the context of the PPBS annual cycle, planning is initiated with the submission of the Joint Strategic Planning Document (JSPD) by the JCS and ends with the Secretary of Defense's issuance of the Defense Guidance which is the document providing guidance for preparation of the Program Objectives Memoranda. The JSPD provides the advice of the JCS to the President, the National Security Council, and the Secretary of Defense on the military strategy and force structure required to attain the national security objectives of the United States.

2. Programming

The basic purpose of the programming phase in PPBS is to translate the strategy into program force structures in terms of time-phased resources requirements including personnel, monies, and material. This is accomplished by systematic approval procedures that "cost out" force objectives for financial and manpower resources five years into the future.

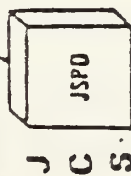
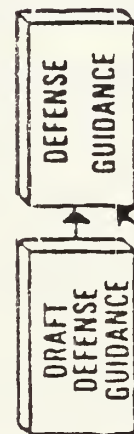
The critical document during the Program Phase is the Program Objectives Memorandum (POM). POM's are prepared by each of the Services

DEPARTMENT OF DEFENSE PLANNING, PROGRAMMING AND BUDGETING SYSTEM



JAN APR MAY JUN JUL-AUG SEP OCT DEC JAN

SECRETARY
OF
DEFENSE



MILITARY
DEPARTMENTS
& AGENCIES



JSPD - JOINT STRATEGIC PLANNING DOCUMENT
JPAM - JOINT PROGRAM ASSESSMENT MEMORANDUM

FYDP SYMBOLS
F - FORCES
M - MANPOWER
\$ - DOLLARS
□ - YEARS



Figure 7. DoD Planning, Programming and Budgeting System

in response to the Defense Guidance from SECDEF. The purpose of a POM is to express total program requirements in terms of force structure, manpower, material and costs, to satisfy all assigned functions and responsibilities during the period of the Five Year Defense Plan. The POM provides rationale for changes from the approved FYDP base and is the primary means of requesting revision to the SECDEF approved programs as published in the FYDP.

About 30 days after the Service's publish their Program Objective Memoranda, the JCS issue the Joint Program Assessment Memorandum (JPAM). The JPAM gives the views of the Joint Chiefs on the adequacy of the composite force and resource levels presented in the Service POMs. The SECDEF considers the Joint Chief's analyses when deciding program issues during the summer issue cycle preceding final approval of Service POMs and the drafting of Program Decision Memoranda (PDM).

As a prelude to the promulgation of the Program Decision Memoranda (PDM), program issues related to force levels, system acquisition, and rates and levels of support are addressed by the OSD and Service Staffs in issue papers which are OSD analyses of annual POM submittals. SECDEF decisions resulting from this review process are promulgated in the Program Decision Memorandum (PDM). Major issues identified in the PDM are discussed by the Service Chiefs, Service Secretaries, and SECDEF.

3. Budgeting

Budgeting is the final phase in the Planning, Programming, Budgeting cycle. The annual budget expresses the financial requirements necessary to support approved programs which were developed during the preceding phases of planning and programming. It is through the

budget that planning and programming are translated into annual funding requirements.

Budget Estimates are submitted to OSD for analyses. After the analyses, the SECDEF holds a series of budget hearings attended by DoD components, the OJCS, and OMB. These hearings are used by SECDEF to formulate his decisions on Decision Package Sets (DPS), which have been prepared by OSD. After OSD issues the annual DPSs, the Services and OJCS provide comments on the DPSs to SECDEF. These comments received from the various components are used by OSD to prepare revised DPSs. At this point, the Budget Estimate is finalized, which after approval by the SECDEF is submitted to OMB for incorporation into the President's Budget.

V. WORK UNIT MEASUREMENT

A. BACKGROUND

For many years the Department of Defense, along with many industries in the private sector, has recognized the importance of quantifying the duration of manual activity to determine the "should take" time to perform that activity, and for establishing a standard method of accomplishment and an associated time value that can be applied whenever and wherever the task or job occurs. Associating of predetermined times to work being measured is standard time data and is generally accepted as the most efficient and productive technique of work measurement. [Ref. 6] DoD, in the late 1960s, began a program to consolidate existing standard data into a common format and publish it so that a single source of standard time data would be available to all DoD activities. This task was completed in 1974 with the publication of DoD 5010.15.1-M, Standardization of Work Measurement. The program has successfully provided a single source of standard time data for use throughout DoD, and efforts to enlarge the coverage and improve the quality of the data are continuing.

As the quantity of standard time data grew and their use increased, problems began to appear. Primarily, the ability to store, search, and retrieve data became increasingly difficult, costly and time consuming. Many of the benefits gained from the use of the data were eroded by the sheer volume of data that had to be stored, searched, retrieved and manipulated.

In the late 1970s a study was initiated to determine a more economical and efficient means of handling standard time data. A method was

needed that would free the work measurement analyst/industrial engineer from the time consuming manual application and maintenance of standard time data so that more time could be devoted to other efforts to improve DoD productivity, e.g., cost reduction, performance analysis, methods improvement. Utilization of a computer as an aid toward the generation of time standards appeared to be the most logical and effective approach to achieve this objective.

In the fall of 1978, DoD contracted with Computer Sciences Corporation to conduct a study to determine the feasibility of computer-aided application of standard time data. Following a review and evaluation of the study, it was concluded that a computer-aided system to establish time standards was not only desirable but feasible as well. Specifications, requirements, and details of a proposal to accomplish the automation of a standard time data application system were developed and a Request for Proposals (RFP) was issued in the spring of 1981. This resulted in the award of a contract to Computer Sciences Corporation, INFONET in September of 1981. This contract was for the initial development, testing, evaluation, and implementation on CSC timesharing (INFONET) of the Defense Computer Aided Standard Data Application System (DCASDAS), more simply called CATS (Computer Aided Time Standards).

B. CATS SUMMARY

CATS provides users with a computer-aided methodology to rapidly find and systematically use standard time data and existing standards to construct new time standards. Various data bases and files containing data essential to the construction of these standards can be

accessed through a remote computer terminal. The operations are performed in an interactive mode.

The prime objective in the design of CATS was to provide, in a user-friendly, conversational format, the means to rapidly find and retrieve work measurement data and to perform the required mathematical computations. Thus, much of the tedium and ineffectiveness inherent in the manual accomplishment of these functions was eliminated. [Ref. 7]

Authorized standard time data and standards will now be available to all DoD users. This capability provides users access to a much wider range of data in a much faster mode than has been previously possible. CATS uses a series of menus, prompts, and instructions displayed at the terminal to direct the operator to appropriate standard time data or standards and then, when the data is found, leads the operator through the necessary processes to construct a new standard.

Procedures to assure control and access to the data bases are established by the using DoD proprietary component. Access as well as the capability to change or modify any data rests with the various system managers. Data stored in any of the "local" data bases can be made available for review for possible inclusion in the DoD data base at the discretion of the system managers through the telecommunication capabilities of CATS.

An essential function of this system is the rapid generation of high-level standards for staffing determinations, staffing projections, and work planning and control. The system will accomplish this by allowing application of locally developed elements or standards as an integral part of its operation.

To increase the flexibility of operation, the development is modular so that "add ons" designed to enhance operations can be made part of the system quickly and inexpensively. Some of the possible "add on" modules are a procedure for developing standard costs, a technique for making an interactive real time cost or procedure comparison, and the capability to automatically determine the effects of efficiency or productivity improvements.

CATS, as developed by CSC, will operate initially on the INFONET timesharing network and will utilize the MANAGE data base management system. By operating on INFONET, worldwide, 24 hour-a-day access to the system is available along with the technical support available from such an organization. By using a common network, DoD components have access to a much larger quantity of standard data elements and standards. It should be noted that the system is designed so that it can be converted for use with other data base management systems, either "in-house" or another timesharing service.

C. METHODOLOGY

As previously stated, CATS could be used either through the CSC INFONET timesharing mode or through an "in-house" mode given that ample computer hardware was available. The initial CATS cost-benefit analysis supported the idea that cost savings could be maximized if the end user could load the system locally. The Marine Corps is currently converting to a data base management concept at its data processing installations and is currently in the process of buying the new hardware required. This concept allows for the arrangement of data in a hierarchical structure that provides for real-time processing and on-line inquiry.

The new large mainframe AMDAHL computers are already in place and operating in Albany, Washington and Kansas City, and delivery to the remaining sites is in the near future.

If the CATS data base management system was locally available at the Depot Maintenance Activities, a program could be written to extract the total time and skill levels required in the major rebuild of each piece of ground equipment. When coupled with the total manhours resident in the personnel data base at each depot, one has all the input coefficients needed for the optimization of the workload within the Master Work Schedule via a linear program utilization.

VI. FORECASTING REBUILD REQUIREMENTS

A. BACKGROUND

Marine Corps Order P4790.1 established MIMMS as the ground equipment maintenance program throughout the Marine Corps. MIMMS is an integrated management system encompassing all equipment commodity, based on standard policies and procedures. These policies and procedures are applicable at all levels of command and echelons of maintenance. When properly used, it contributes significantly to increased equipment readiness and reduces consumption of maintenance resources. It is user-oriented and designed to interface with other logistical systems. [Ref. 8]

MIMMS is comprised of three subsystems that include Headquarters, Depot and Field as depicted in Figure 8.

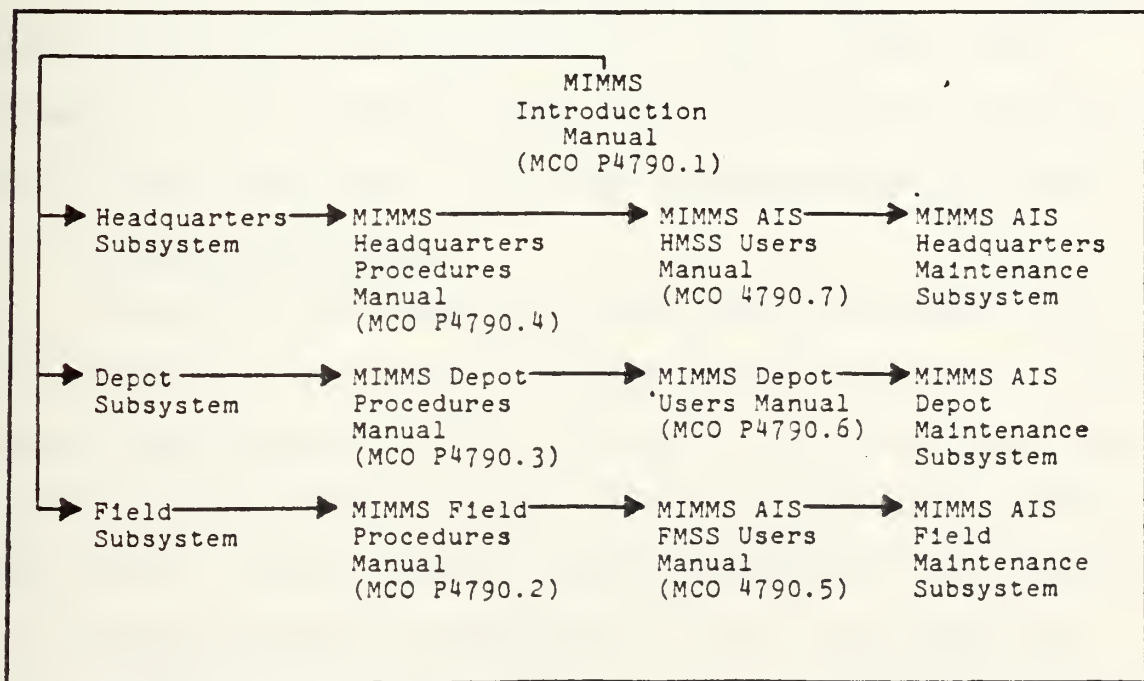


Figure 8. MIMMS Subsystems

1. Headquarters Subsystem

The Headquarters subsystem was developed to support and guide personnel at Headquarters Marine Corps. The Automated Information System (AIS) subsystem supporting the Headquarters maintenance management is the MIMMS AIS Headquarters Maintenance System (HMSS).

2. Depot Subsystem

The Depot subsystem supports the Depot maintenance effort and it utilizes the Depot Maintenance Subsystem (DMSS) as its supporting AIS subsystem.

3. Field Subsystem

The Field subsystem supports the end user in the Fleet Marine Force. Its supporting AIS subsystem is called the Field Maintenance Subsystem (FMSS).

B. METHODOLOGY

The relatively small size of the Marine Corps allows for the compilation of large amounts of historical data on ground equipment items. Presently, all serial numbered items, including Principal End Items and Secondary Depot Repairables, are tracked throughout their life cycle.

1. Accumulation of Data

The major problem remaining at this point in the model is the identification and transferring of appropriate historical records to the logistic support sponsors at Albany, Georgia. This can be accomplished via the maintenance engineering code currently being used in the Fleet Marine Force. This code presently identifies equipment records that are to be extracted and sent to Headquarters for use in the Headquarters Maintenance Subsystem on a periodic basis. This code could also be

used, with very little program modification, to identify and segregate records to be sent to Albany. Once accomplished, this will allow for the aggregation and storage of all maintenance data on all Marine Corps Principal End Items and Secondary Repairables at one common location.

2. Multiple Linear Regression

It is at this point that the mathematical techniques of multiple regression can be brought into play. Regression has become a widely accepted tool for cost analysis and forecasting, and it is frequently used to develop estimating relationships within the Department of Defense. The technique of regression analysis can be thought of as consisting of two distinct stages. The first is that of estimating the constant and coefficients of the equation, and the second is that of inferring the reliability and significance of the results of the estimate on the basis of assumed, and to a degree verifiable, properties possessed by the data and the results. Regression analysis as a technique is applicable only to the two stages performed together. [Ref. 9]

The form of the relationships between the dependent and the explanatory variables will always depend on the particular problem under consideration. It may reflect either an underlying physical law or a structural relationship. The linear model addressed in this thesis will be of the form:

$$z = ax+by+c$$

where z is the dependent variable (the variable we are attempting to estimate) and x and y are both explanatory variables. These explanatory variables will be considered as engine operating time and total labor hours respectively. The symbols a and b are the regression coefficients,

and the symbol c is the regression constant. In layman's language, if we process all the historical maintenance data for a particular piece of ground equipment through a multiple regression program, the historical representations of engine operating time (x) and total labor hours (y) to major rebuild will yield the regression coefficients a and b , along with the regression constant c . Then, given the engine operating time (x) and total labor hours (y) of a like piece of equipment still in use, we can estimate the time (z) when this given piece of equipment will require overhaul. This date will then be checked against the service exit date for that particular serial numbered item to assure its candidacy for rebuild. The regression analysis will also yield information than can be used to infer the confidence of our prediction. This work will all be instrumental in attempting to calculate approximately the quantity of each type of equipment requiring rebuild over the Five Year Defense Plan. It should be noted at this time as a by-product, these quantities could be input into the Interim Material Management Programming Model for use in the requirements calculations as previously stated.

Simplicity dictates that I use the actual output of the regression analysis as the input to the latter stages of this model. However, one should realize that these quantities of Principle End Items and Secondary Depot Repairables may be altered before induction into any linear program.

3. Alterations of Regression Analysis

There are many managerial decisions that might alter the actual output quantities of the regression analysis. The following list shows five such decisions that a logistics planner might have to account for:

1. Particular priority to a given type of equipment to meet requirement shortfalls.

2. Transportation delays of the equipment to the supporting Depot Maintenance Activity.
3. Carcass returns left over from previous year.
4. Alteration of Master Work Schedule to satisfy some special project.
5. Rebuild requirements of other services for like equipment.

Of these particular five, the first four are more or less self-explanatory. However, other services' rebuild requirements should be embellished upon.

- a. Nonconsumable Item Program

During February 1974, the Joint Logistics Commanders of the Department of Defense directed that their Joint Policy Coordinating Group for Defense Integrated Material Management (JPCG/DIMM) eliminate unnecessary duplication in the management and logistics support of multi-used nonconsumable items. The JPCG/DIMM identified material management of all reparable nonconsumable items used by two or more services and assigned the material management responsibilities in favor of the service with the largest maintenance and depot maintenance capability to support the item. This assignment included functions of computations of replacement and overhaul requirements, budgeting and funding, procurement, receipt, storage and issue, depot level maintenance, cataloguing and disposal. [Ref. 10]

Implementation of this program resulted in the establishment of the Nonconsumable Item Program in March of 1978. A lead service was designated the Primary Inventory Control Activity (PICA) for each nonconsumable item on file at the Defense Logistics Service Center with the exception of multi-used, nonconsumable items identified as interchangeable and substitutable (I&S) and items under management cognizance of the Defense Nuclear Agency (DNA). A one-digit code was added to the

DLSC files. An alpha code designed where and by whom rebuild could be performed and a numeric code identified on agreed-to type of support between the Primary Inventory Control Activity and the Secondary Inventory Control Activity (SICA).

b. Secondary Inventory Control Activity (SICA)

The responsibilities of the Secondary Inventory Control Activity are as follows:

1. Submitting request for procurement of items to the assigned PICA.
2. Notifying the PICA of service excesses and taking appropriate disposition action.
3. Negotiating with the PICA the degree of support to be provided.
4. Providing the PICA, on a cyclic basis, projected requisitioning requirements and projected unserviceable carcass returns.
5. Initiating action to update the federal file with the applicable Nonconsumable Item Material Support Code (NIMSC).
6. Submitting to the PICA proposed cataloguing changes to data which is under the PICA's cognizance.
7. Establishing service requirements.
8. Budgeting and funding for service requirements in accordance with material support codes assigned.

The size limitations of the Marine Corps dictate that it be designated the Secondary Inventory Control Activity on virtually every piece of equipment contained within the Tables of Equipment. For this reason, it is of utmost importance that the depots keep in close contact with their representatives at the Maintenance Interservice Support Management Office (MISMO).

c. Maintenance Interservice Support Management Office (MISMO)

The MISMO is a collection of interservice representatives that serve as the communications link between PICA - SICA activities. It is within this office that the Marine Corps makes agreements to rebuild much of their own ground equipment at their own Depot Maintenance Activities. They also make agreements with other services to handle some of the overflow created by other services. Marine Corps Master Work Schedule planners at Albany must keep in constant communication with their MISMO representatives in order to effect meaningful alterations to the regression analysis output.

VII. MODEL ANALYSIS

The following paragraphs are a synopsis of the FORTRAN program that was personally written and utilized to calculate the regression coefficients used to estimate the number of carcass returns that would be candidates for rebuild during each year of the Five Year Defense Plan. In addition, the results of a survey used to establish objective function coefficients for the final linear program execution are provided.

A. GENERATION OF MAINTENANCE DATA

The purpose of this paper is to demonstrate some quantitative methods for estimation and optimization. Because of this, it was deemed unnecessary to utilize actual maintenance data. A random number generator was used to generate standard normal deviates which were in turn transformed into normal random deviates. These deviates were used to emulate time to major rebuild, equipment operating time, and total labor hours spent in third and fourth echelon maintenance at the Force Service Support Groups (FSSG's) before rebuild. This set of data represented information that would be available within the MIMMS AIS Depot Maintenance Subsystem and was utilized as input to a multiple linear regression subroutine. The outputs of this program execution were the regression coefficients contained in Figure 9.

A second set of deviates were then generated to emulate equipment operating times and total labor hours of Marine Corps ground equipment presently active within the FMF. The information is presently available within the MIMMS AIS Field Maintenance Subsystem. This data was then

REGRESSION COEFFICIENTS

	<u>TANKS</u>	<u>AMTRACKS</u>	<u>RADIOS</u>	<u>TRUCKS</u>	<u>HOWITZERS</u>
BETA (1) =	-0.003725	0.101428	-0.081089	0.115988	-0.037267
BETA (2) =	0.221236	-0.094033	0.312172	-0.010870	0.159418
BETA (3) =	17.257538	31.995407	17.386505	26.666733	17.246368

ESTIMATED NUMBER OF MONTHS BEFORE MAJOR REBUILD

<u>TANKS</u>	<u>AMTRACKS</u>	<u>RADIOS</u>	<u>TRUCKS</u>	<u>HOWITZERS</u>
7.92	24.96	16.09	22.90	48.35
28.68	46.06	1.68	41.47	48.48
9.80	30.48	15.32	58.05	20.97
14.69	25.43	57.61	13.05	15.39
21.86	50.39	43.85	5.00	36.96
33.81	35.82	32.79	24.75	19.87
49.25	34.06	38.49	43.12	26.91
26.00	17.23	15.19	22.20	61.02
21.82	10.40	35.21	20.92	12.26
1.93	24.00	42.29	29.91	34.36
37.67	48.48	17.74	45.32	30.43
40.02	43.43	4.95	42.50	3.57
58.12	33.32	17.07	33.06	1.43
17.81	3.60	62.91	24.14	36.22
17.54	30.90	16.60	31.55	25.61
44.36	6.01	2.27	19.84	24.99
28.07	11.82	94.66	6.43	22.39
18.80	9.01	16.87	54.58	20.50
9.85	23.94	62.87	44.61	9.10
44.00	32.20	21.63	24.64	4.52
5.93	33.95	7.27	37.66	32.37
49.23	25.10	33.99	4.11	12.98
64.61	44.79	42.25	58.46	3.83
2.22	35.63	42.21	13.45	22.07
5.25	20.52	70.55	23.40	41.04
10.93	45.04	46.25	19.64	19.44
22.63	34.50	48.09	23.67	32.48
24.31	52.42	33.58	20.89	24.72
11.87	36.52	21.04	4.07	12.42
49.96	18.64	5.64	8.24	5.37
32.60	35.66	40.59	30.54	33.70
29.65	51.71	39.76	42.09	18.61
33.00	34.84	35.54	48.34	42.56
57.01	20.00	2.88	47.39	15.07
10.22	47.62	35.20	29.35	13.89
8.49	35.50	5.93	42.14	11.18
27.77	41.62	76.77	42.08	6.88
0.01	36.53	39.82	26.86	5.32
44.35	13.04	94.30	54.00	16.60
53.22	34.15	7.06	19.30	2.82
27.19	17.99	54.40	23.38	45.61
53.72	1.53	35.01	17.70	29.35
55.06	38.95	47.22	25.69	27.84
9.56	53.12	43.84	46.16	8.58
24.08	13.12	13.07	33.57	2.24
52.10	31.35	10.63	14.06	8.05
7.40	49.37	53.54	40.27	26.73
8.41	27.96	27.11	36.10	40.17
8.24	22.86	15.21	13.03	3.65
12.17	50.70	24.66	10.08	3.80

Figure 9. Regression Coefficients and Estimated Number of Months Before Major Rebuild

applied to the above mentioned regression coefficients yielding the approximate month that the individual serialized equipment would require major rebuild. These months to major rebuild are shown in Figure 9 and represent the number of months until a piece of equipment, presently in use, will require major overhaul.

The estimated number of months to major rebuild were then aggregated by commodity within five different twelve month intervals yielding the results shown in Figure 10. These results were then used as input to the linear programming model.

It should be noted that due to the scope of this paper, only five major categories are presented herein:

1. Tanks
2. Amtracks
3. Radios
4. Trucks
5. Howitzers

However, these quantitative techniques apply to all categories of Marine Corps ground equipment as well as all models within the categories.

B. OBJECTIVE FUNCTION

Before the linear program can be executed using the rebuild candidates, skill level hours available and skill level hours required, an objective function must be formulated. Obviously, the five major commodities are the variables but the corresponding coefficients must be determined. These coefficients represent the level of importance associated with the rebuild of each commodity, and are used to insure the maximization of depot productivity for the labor skill levels

AGGREGATED REBUILD CANDIDATES

	<u>TANKS</u>	<u>AMTRACKS</u>	<u>RADIOS</u>	<u>TRUCKS</u>	<u>HOWITZERS</u>
YEAR (0)	16	6	9	6	15
YEAR (1)	8	10	11	15	14
YEAR (2)	10	18	9	11	12
YEAR (3)	6	9	11	13	6
YEAR (4)	9	7	4	5	2

Figure 10. Aggregated Rebuild Candidates

available. A survey was used to determine these objective function coefficients.

Twenty Marine and Army officers were asked to rank the aforementioned commodities in their order of importance to the ground forces. The method utilized to analyze these rankings is one in which ordinal information furnished by judges is combined with a model of judge behavior to obtain, ultimately, an interval scale for the instances (commodities). Thus, while an individual judge may be asked only to rank instances, collective inputs from many judges permit an interval scale to be inferred without arbitrary scoring. Models approaching scale development from ordinal data vary depending upon the assumptions made. The model utilized herein is described in Ref. 11.

A FORTRAN program was then written to carry out the mathematics required by the reference. Once these results were calculated, a linear transformation was then applied to initialize the lowest value to 1.0. These final objective function coefficients are shown in Figure 11 along with the corresponding $f(i,j)$, $p(i,j)$ and $z(i,j)$ matrices required in the calculations. The $f(i,j)$ matrix shows the number of times that the i instance was ranked above the j instance by all judges. The $p(i,j)$ matrix then breaks these values into probabilities through the use of the formula

$$p(i,j) = f(i,j) / (f(i,j) + f(j,i))$$

Finally, the $z(i,j)$ matrix is computed by standard normalizing the $p(i,j)$ matrix. It should be noted at this point that the linear transformation chosen in the project is not unique and will not yield unique results when the objective function and input tableau are input to the

F(I,J) MATRIX

0.0	14.0	20.0	24.0	24.0
26.0	0.0	22.0	20.0	24.0
20.0	18.0	0.0	18.0	20.0
16.0	20.0	22.0	0.0	24.0
16.0	16.0	20.0	16.0	0.0

P(I,J) MATRIX

0.50	0.35	0.50	0.60	0.60
0.65	0.50	0.55	0.50	0.60
0.50	0.45	0.50	0.45	0.50
0.40	0.50	0.55	0.50	0.60
0.40	0.40	0.50	0.40	0.50

Z(I,J) MATRIX

0.0	-0.39	0.0	0.25	0.25
0.39	0.0	0.13	0.0	0.25
0.0	-0.13	0.0	-0.13	0.0
-0.25	0.0	0.13	0.0	0.25
-0.25	-0.25	0.0	-0.25	0.0

OBJECTIVE FUNCTION COEFFICIENTS

<u>TANKS</u>	<u>AMTRACKS</u>	<u>RADIOS</u>	<u>TRUCKS</u>	<u>HOWITZERS</u>
1.1763	1.3049	1.1017	1.1771	1.0000

Figure 11. Objective Function Coefficients

linear program. This is merely one of the many ways of deriving the objective function coefficients.

C. LINEAR PROGRAMMING

Linear programming has long been recognized as a mathematical tool which allows for the accomplishment of some mission through the most efficient use of resources available. [Ref. 12] These linear programming packages are commercially available and are widely used throughout the Department of Defense. In this project, the mission is to find the optimal mix of equipment to rebuild utilizing the resources, labor hours within different skill levels, available at the Depot Maintenance Activity. While one would intrinsically expect to achieve integer answers, the linear program will more than likely yield fractionalized results. However, since the quantities we are dealing with are relatively large compared to zero or one, the results can be rounded down to the next smaller integer to insure compliance with existing labor availability constraints. This can be accomplished without significant loss of accuracy and is perfectly acceptable since we are only interested in estimating numbers of equipment to be rebuilt.

The tableau of coefficients to be input into the linear program is pictured in Figure 12. The column headings (i.e., tanks, amtracks, radios, trucks, howitzers) represent the variables we are attempting to maximize. The coefficients under the column headings represent the number of hours within each skill level required to rebuild the item represented by that particular column heading. This information was extracted from the CATS files previously mentioned. The coefficients

MAXIMIZE $1.1763X(1) + 1.3049X(2) + 1.1017X(3) + 1.1771X(4) + 1.0000X(5)$

Subject To:

<u>X(1)</u> <u>Tanks</u>	<u>X(2)</u> <u>ArmTrucks</u>	<u>X(3)</u> <u>Radlos</u>	<u>X(4)</u> <u>Trucks</u>	<u>X(5)</u> <u>Howitzers</u>	
20	25	42	28	30	12480 (WG- 6 Electrician)
28	42	35	25	40	14560 (WG- 7 Electrician)
43	22	26	47	40	10400 (WG- 8 Electrician)
29	34	28	44	32	20800 (WG- 9 Electrician)
23	26	41	33	48	12480 (WG-10 Electrician)
24	26	38	25	43	14560 (WG-11 Electrician)
34	46	27	23	21	20800 (WG-12 Electrician)
30	20	26	43	37	16640 (WG- 6 Mechanic)
28	24	34	42	48	18720 (WG- 7 Mechanic)
34	43	41	22	28	20800 (WG- 8 Mechanic)
31	23	26	46	42	14560 (WG- 9 Mechanic)
20	29	35	43	27	10400 (WG-10 Mechanic)
25	35	42	30	22	16640 (WG-11 Mechanic)
32	32	40	28	24	10400 (WG-12 Mechanic)
45	40	23	27	34	20800 (WG- 6 Armorer)
27	35	37	32	20	12480 (WG- 7 Armorer)
21	43	48	29	30	20800 (WG- 8 Armorer)
20	34	36	42	27	14560 (WG- 9 Armorer)
43	34	38	22	44	10400 (WG-10 Armorer)
25	23	38	42	21	18720 (WG-11 Armorer)
30	42	21	22	29	16640 (WG-12 Armorer)
36	28	20	42	47	12480 (WG- 6 Machinist)
31	46	27	37	30	20800 (WG- 7 Machinist)
25	26	38	43	48	10400 (WG- 8 Machinist)
34	35	22	47	27	12480 (WG- 9 Machinist)
23	21	28	40	31	16640 (WG-10 Machinist)
24	42	43	30	32	16640 (WG-11 Machinist)
20	31	43	29	22	18720 (WG-12 Machinist)
29	34	37	28	25	12480 (WG- 6 Calibration)
21	45	46	31	30	12480 (WG- 7 Calibration)
37	41	28	28	31	18720 (WG- 8 Calibration)
26	35	23	48	23	12480 (WG- 9 Calibration)
30	37	23	46	34	16640 (WG-10 Calibration)
29	28	46	31	30	14560 (WG-11 Calibration)
20	36	34	32	29	12480 (WG-12 Calibration)
37	47	31	30	25	20800 (WG- 6 Hydraulics)
23	24	45	47	33	16640 (WG- 7 Hydraulics)
34	30	26	42	40	18700 (WG- 8 Hydraulics)
25	28	23	40	34	16640 (WG- 9 Hydraulics)
21	45	44	34	27	12480 (WG-10 Hydraulics)
20	38	34	41	29	14560 (WG-11 Hydraulics)
27	37	41	49	33	18720 (WG-12 Hydraulics)

Figure 12. Linear Programming Tableau

on the right hand side corresponding to the skill level hours required, represent the total skill level hours available and are obtained from the DMA's personnel files.

D. DMA COST ESTIMATION

Once the final results are obtained yielding the optimal mix for rebuild within each commodity for the budget year, the process must be executed for each of the four subsequent years within the Five Year Defense Plan. Upon completion, these results are then multiplied by the historical average cost of rebuild for each separate commodity area thus providing more accurate quantitative estimates for the budget planners.

E. FUTURE ENHANCEMENTS

Several enhancements could be made to this model in an effort to derive more accurate estimates of both costs and rebuild candidates. Since a multiple linear regression package was utilized, any number of explanatory variables (in addition to labor hours and engine operating time) could be used to provide better accuracy. One would merely have to peruse the MIMMS data files available to obtain likely candidates that could have some impact on mean time between overhauls. Also, a regression could be executed in which total rebuild cost would be regressed upon total labor hours and engine operating time. This would probably yield a better cost estimate since it would use data from the actual equipment being rebuilt rather than an average cost to rebuild.

Several more sophisticated enhancements could be made to the current model. One such improvement would provide for the utilization of an

integer linear programming model, serving to further minimize the amount of labor waste within the Master Work Schedule. A cost benefit analysis could prove that the actual increased computer cost of achieving integer results is offset by an increase in productivity within the DMA. Another improvement could provide for a budget planners "knob". This would allow for the comparison of varying levels of depot productivity based on various budget levels. A capability of this type would require the inclusion of an additional vector containing the mean cost of repairs for each commodity area. This vector, along with the input budget level, would then act as another constraint for the linear program.

VIII. CONCLUSIONS

This project was constructed in an attempt to familiarize Marine Corps officials within the Supply community with the mathematical tools available to their commands. In retrospect, this thesis combined information from systems already in and under development, MIMMS and CATS, and applied it to some of the basic tools available to the operations research analyst: random number generation, multiple linear regression, survey analysis and linear programming. Although all of these concepts have been theoretically proven within the academician's world, very few of them are actually put into practice in everyday use. I have shown that these quantitative techniques can be used to significantly improve efficiency at the Depot Maintenance Activity by optimizing the Master Work Schedule through better resource utilization. A follow-on advantage allows these results to actually estimate the total costs within the Depot for the current year and any number of subsequent years. This type of information could prove invaluable to budget planners at the Headquarters level.

This topic was selected for several different reasons. First, it represented an area of some concern to the Supply Operations Division within the Inventory Control Point at Albany, Georgia. [Ref. 13] Secondly, it allowed the presentation of several mathematical techniques in a somewhat modularized approach. The individual reader should be able to conceptualize personal, job-related applications utilizing some of these methods. Finally, this topic provided a vehicle to showcase

the abilities of the operations analyst. It is felt that this type of educational talent should actually be placed at the heart of the aggregated data (the ICP and the DMA's within the Supply field). This would allow for more efficient utilization of the models currently in use through immediate feedback of result analysis. Also, the analyst would have the time and availability to produce newer and better model utilizations. This data availability could serve to effectively minimize the amount of non-productive time for the "on-call" analyst.

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10      CONTINUE
DO 20 I=1,100
  TLH(I)=TLF(I)*SD(1)+MEAN(1)
  TEOT(I)=TEOT(I)*SD(2)+MEAN(2)
  TMTBF(I)=TMTBF(I)*SD(3)+MEAN(3)
  ALH(I)=ALH(I)*SD(4)+MEAN(4)
  AECT(I)=AECT(I)*SD(5)+MEAN(5)
  AMTBF(I)=AMTBF(I)*SD(6)+MEAN(6)
  RLH(I)=RLH(I)*SD(7)+MEAN(7)
  REOT(I)=REOT(I)*SD(8)+MEAN(8)
  RMTBF(I)=RMTBF(I)*SD(9)+MEAN(9)
  DLH(I)=DLH(I)*SD(10)+MEAN(10)
  DECT(I)=DECT(I)*SD(11)+MEAN(11)
  DMTBF(I)=DMTBF(I)*SD(12)+MEAN(12)
  HLH(I)=HLH(I)*SD(13)+MEAN(13)
  HEOT(I)=HEOT(I)*SD(14)+MEAN(14)
  HMTBF(I)=HMTBF(I)*SD(15)+MEAN(15)

20      CONTINUE
DO 30 I=1,100
  TXY(I,1)=TLH(I)
  AXY(I,1)=ALH(I)
  RXY(I,1)=RLH(I)
  DXY(I,1)=DLH(I)
  HXY(I,1)=HLH(I)
  TXY(I,2)=TEOT(I)
  AXY(I,2)=AECT(I)
  RXY(I,2)=REOT(I)
  DXY(I,2)=DECT(I)
  HXY(I,2)=HEOT(I)
  TXY(I,3)=TMTBF(I)
  AXY(I,3)=AMTBF(I)
  RXY(I,3)=RMTBF(I)
  DXY(I,3)=DMTBF(I)
  HXY(I,3)=HMTBF(I)

30      CONTINUE
CALL RLLMV(TXY,100,100,2,0,TBETA,TRMAX,ITER,ITRANK,WK,IER)
CALL RLLMV(AXY,100,100,2,0,ABETA,ARMAX,ITER,IARANK,WK,IER)
CALL RLLMV(RXY,100,100,2,0,RBETA,RRMAX,ITER,IRRANK,WK,IER)
CALL RLLMV(DXY,100,100,2,0,DBETA,DRMAX,ITER,IDRANK,WK,IER)
WRITE(6,700)
700      WRITE(6,705)
705      WRITE(6,710)
710      WRITE(6,720)
      FORMAT(34X,'REGRESSION COEFFICIENTS')
      FORMAT('+',23X,'TANKS',9X,'AMTRACKS',7X,'RACIOS',10X,'TRUCKS',
        *7X,'HOWITZERS',)

```



```

720      FORMAT('+',15X,'-----',7X,'-----',6X,'-----',8X,
*        '0',6X,'-----')
DO 40 I=1,3
  WRITE(6,730) I, TBETA(I), ABETA(I), RBETA(I), DBETA(I), HBETA(I)
  FORMAT(2X,'BETA(',11,')=',5(5X,F10.6))
CONTINUE
ND=50
CALL GGNML(CSEED,NO,TLH)
CALL GGNML(CSEED,NO,TECT)
CALL GGNML(CSEED,NO,ALH)
CALL GGNML(CSEED,NO,AECT)
CALL GGNML(CSEED,NO,RLH)
CALL GGNML(CSEED,NO,REOT)
CALL GGNML(CSEED,NO,DLH)
CALL GGNML(CSEED,NO,DEOT)
CALL GGNML(CSEED,NO,HLH)
CALL GGNML(CSEED,NO,HEOT)
DO 50 I=1,50
  TLH(I)=TLH(I)*SD(1)+MEAN(1)
  TECT(I)=TECT(I)*SD(2)+MEAN(2)
  ALH(I)=ALH(I)*SD(4)+MEAN(4)
  AECT(I)=AECT(I)*SD(5)+MEAN(5)
  RLH(I)=RLH(I)*SD(7)+MEAN(7)
  REOT(I)=REOT(I)*SD(8)+MEAN(8)
  DLH(I)=DLH(I)*SD(10)+MEAN(10)
  DEOT(I)=DEOT(I)*SD(11)+MEAN(11)
  HLH(I)=HLH(I)*SD(13)+MEAN(13)
  HEOT(I)=HEOT(I)*SD(14)+MEAN(14)
CONTINUE
WRITE(6,740)
WRITE(6,745)
WRITE(6,760)
740      FORMAT('///',20X,'ESTIMATED NUMBER OF MCNTHS BEFORE MAJOR REBUILD'
*        ')
745      FORMAT('+',15X,'-----')
750      FORMAT(' ',10X,'TANKS',8X,'AMTRACKS',8X,'RADIOS',
*        '9X',8X,'TRUCKS',8X,'HOWITZERS',
*        '9X',8X,'-----',8X,'-----',8X,'-----')
DO 60 I=1,50
  TMTBF(I)=TBETA(1)*TLH(I)+TBETA(2)*TECT(I)+TBETA(3)
  AMTBF(I)=ABETA(1)*ALH(I)+ABETA(2)*AECT(I)+ABETA(3)
  DMTBF(I)=DBETA(1)*DLH(I)+DBETA(2)*DEOT(I)+DBETA(3)
  HMTBF(I)=HBETA(1)*HLH(I)+HBETA(2)*HEOT(I)+HBETA(3)
  TMTBF(I)=ABS(TMTBF(I))

```



```

AMTBF(I)=ABS(AMTBF(I))
RMTBF(I)=ABS(RMTBF(I))
DMTBF(I)=ABS(DMTBF(I))
HMTBF(I)=ABS(HMTBF(I))
WRITE(6,770) TMTBF(I),AMTBF(I),RMTBF(I),DMTBF(I),HMTBF(I)
FORMAT(' ',5(X,F10.2))
CONTINUE
J=1
DO 70 I=1,50
IF((TMTBF(I).GT.0.).AND.(TMTBF(I).LE.12.)) YR0(J)=YR0(J)+1
IF((TMTBF(I).GT.12.).AND.(TMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
IF((TMTBF(I).GT.24.).AND.(TMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
IF((TMTBF(I).GT.36.).AND.(TMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
IF((TMTBF(I).GT.48.).AND.(TMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
CONTINUE
J=J+1
DO 70 I=1,50
IF((AMTBF(I).GT.0.).AND.(AMTBF(I).LE.12.)) YR0(J)=YR0(J)+1
IF((AMTBF(I).GT.12.).AND.(AMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
IF((AMTBF(I).GT.24.).AND.(AMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
IF((AMTBF(I).GT.36.).AND.(AMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
IF((AMTBF(I).GT.48.).AND.(AMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
CONTINUE
J=J+1
DO 80 I=1,50
IF((RMTBF(I).GT.0.).AND.(RMTBF(I).LE.12.)) YR0(J)=YR0(J)+1
IF((RMTBF(I).GT.12.).AND.(RMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
IF((RMTBF(I).GT.24.).AND.(RMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
IF((RMTBF(I).GT.36.).AND.(RMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
IF((RMTBF(I).GT.48.).AND.(RMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
CONTINUE
J=J+1
DO 90 I=1,50
IF((DMTBF(I).GT.0.).AND.(DMTBF(I).LE.12.)) YR0(J)=YR0(J)+1
IF((DMTBF(I).GT.12.).AND.(DMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
IF((DMTBF(I).GT.24.).AND.(DMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
IF((DMTBF(I).GT.36.).AND.(DMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
IF((DMTBF(I).GT.48.).AND.(DMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
CONTINUE
J=J+1
DO 100 I=1,50
IF((HMTBF(I).GT.0.).AND.(HMTBF(I).LE.12.)) YR0(J)=YR0(J)+1
IF((HMTBF(I).GT.12.).AND.(HMTBF(I).LE.24.)) YR1(J)=YR1(J)+1
IF((HMTBF(I).GT.24.).AND.(HMTBF(I).LE.36.)) YR2(J)=YR2(J)+1
IF((HMTBF(I).GT.36.).AND.(HMTBF(I).LE.48.)) YR3(J)=YR3(J)+1
IF((HMTBF(I).GT.48.).AND.(HMTBF(I).LE.60.)) YR4(J)=YR4(J)+1
CONTINUE
WRITE(6,800)

```



```

WRITE(6,810)
WRITE(6,750)
WRITE(6,760)
FOR MAT(1,27X, 'AGGREGATED REBUILD CANDIDATES', ///)
WRITE(6,820)
WRITE(6,821)
WRITE(6,822)
WRITE(6,823)
WRITE(6,824)
FORMAT(1X, 'YEAR(0)', 4X, 12, 13X, 12, 13X, 12, 13X, 12, //)
FORMAT(1X, 'YEAR(1)', 4X, 12, 13X, 12, 13X, 12, 13X, 12, 13X, 12, //)
FORMAT(1X, 'YEAR(2)', 4X, 12, 13X, 12, 13X, 12, 13X, 12, 13X, 12, //)
FORMAT(1X, 'YEAR(3)', 4X, 12, 13X, 12, 13X, 12, 13X, 12, 13X, 12, //)
FORMAT(1X, 'YEAR(4)', 4X, 12, 13X, 12, 13X, 12, 13X, 12, 13X, 12, //)
RETURN
END
SUBROUTINE RLLMV (XY, IXY, N, M, IOPT, BETA, REMAX, ITER, IRANK, WK, IER)
INTEGER
REAL
INTEGER
1 REAL
1 DATA
DATA
DATA
MM = M
MP1 = M+1
MP2 = M+2
MP3 = M+3
MP5 = M+5
MP1MR = 1
IRANK = MM
RFLTMP = RELERR
DO 5 I=1, N
XY(I, MP5) = XY(I, MP1)
5 CONTINUE
IF (IOPT.NE.0) GC TO 15
DO 10 I=1, N
XY(I, MP1) = CNE
10 CONTINUE
MM = M+1
MP1 = MM+1
MP2 = MM+2
RLLM0780
RLLM0790
RLLM0800
RLLM0810
RLLM0820
RLLM0830
RLLM0840
RLLM0850
RLLM0860
RLLM0870
RLLM0880
RLLM0890
RLLM0900
RLLM0910
RLLM0920
RLLM0930
RLLM0940
RLLM0950
RLLM0960
RLLM0970
RLLM0980
RLLM0990
RLLM1000
RLLM1010
RLLM1020
RLLM1030
RLLM1040
RLLM1050
RLLM1060
RLLM1070
RLLM1080
SPECIFICATIONS FOR ARGUMENTS
SPECIFICATIONS FOR LOCAL VARIABLES
IPCOL, IPROW, IRANK1, IROW, I, J, KP1, K, LEV, MM, MODE,
MP1MK, MP1MR, MP1, MP2, MP3, MP5, NM1, NP1MR,
BIG, DD, D, FMM, ONE, PIVCT, RELEKR, RELTMP, TOL,
TPIVOT, TWO, VAL, ZERO
TOL/Z3C100000/
BIG/Z7FFFFF/
ZERO/0.0/, ONE/1.0/, TWO/2.0/, RELERR/0.0/
FIRST EXECUTABLE STATEMENT

```



```

MP3 = MM+3
IRANK = MM
FMM = MM
15 DO 20 J=1,N
   XY(J,MP1) = CNE
   XY(J,MP2) = -XY(J,MP5)
   XY(J,MP3) = MM+J
20 CONTINUE
WK(MP1) = ZERO
ITER = 0
IER = 0
DO 25 I=1,MM
   BETA(I) = I
   WK(I) = I
25 CONTINUE
C
   LEV = 1
   K = 0
30 K = K+1
   KPI = K+1
   MP1MK = MP1-K
   MODE = 0
   DO 35 J=K,N
      XY(J,MP5) = ONE
35 CONTINUE
C
40 D = -BIG
   DO 45 J=K,N
      IF (XY(J,MP5).EQ.ZERO) GO TO 45
      DD = ABS(XY(J,MP2))
      IF (DD.LE.D) GO TO 45
      IPCCL = J
      C = DD
45 CONTINUE
   IF (K.GT.1) GO TO 50
   IF (D.GT.TOL) GO TO 50
   REMAX = ZERO
   MODE = 2
   GO TO 205
C
50 D = TCL
   DO 55 I=1,MP1MK
      CC = ABS(XY(IPCCL,I))
      IF (DD.LE.D) GO TO 55
      IPROW = I

```

LEVEL :

DETERMINE THE VECTOR TO ENTER THE
BASIS

TEST FOR ZERO RIGHT-HAND SIDE

DETERMINE THE VECTOR TO LEAVE THE
BASIS

RLLM1090
 RLLM1100
 RLLM1110
 RLLM1120
 RLLM1130
 RLLM1140
 RLLM1150
 RLLM1160
 RLLM1170
 RLLM1180
 RLLM1190
 RLLM1200
 RLLM1210
 RLLM1220
 RLLM1230
 RLLM1240
 RLLM1250
 RLLM1260
 RLLM1270
 RLLM1280
 RLLM1290
 RLLM1300
 RLLM1310
 RLLM1320
 RLLM1330
 RLLM1340
 RLLM1350
 RLLM1360
 RLLM1370
 RLLM1380
 RLLM1390
 RLLM1400
 RLLM1410
 RLLM1420
 RLLM1430
 RLLM1440
 RLLM1450
 RLLM1460
 RLLM1470
 RLLM1480
 RLLM1490
 RLLM1500
 RLLM1510
 RLLM1520
 RLLM1530
 RLLM1540
 RLLM1550
 RLLM1560


```

C
IPCOL = J
D = DD
100 CONTINUE
      IF (D.GT.TOL) GO TO 105
      REMAX = ZERC
      MODE = 3
      GO TO 205
105  IF (XY(IPCOL,MP2).LT.-TOL) GO TO 115
      XY(IPCOL,MP1) = TWC-XY(IPCOL,MP1)
      DO 110 I=MP1MR,MP3
      IF (I.EQ.MP1) GO TO 110
      XY(IPCOL,I) = -XY(IPCOL,I)
110 CONTINUE
      ARRANGE FOR ALL ENTRIES IN PIVOT
      COLUMN (EXCEPT PIVOT) TO BE
      NEGATIVE
115  DO 125 I=MP1MR,MM
      IF (XY(IPCOL,I).LT.TOL) GO TO 125
      DO 120 J=1,N
      XY(J,MP1) = XY(J,MP1)+TWC*XY(J,I)
      XY(J,I) = -XY(J,I)
120 CONTINUE
      WK(I) = -WK(I)
125 CONTINUE
      IPROW = MP1
      GO TO 180
130  IF (IRANK1.EQ.N) GO TO 205
      IF (IPCOL.EC.N) GO TO 140
C
      DO 135 I=MP1MR,MP3
      D = XY(IPCOL,I)
      XY(IPCOL,I) = XY(N,I)
      XY(N,I) = D
135 CONTINUE
140 NM1 = N-1
C
      LEV = 3
      LEVEL 3
      DETERMINE THE VECTOR TO ENTER THE
      BASIS
145  D = -TCL
      VAL = TWO*XY(N,MP2)
      DO 155 J=IRANK1,NM1
      IF (XY(J,MP2).GE.D) GO TO 150
      IPCOL = J
      D = XY(J,MP2)
      MODE = 0
      GO TO 155

```

RLLM2050
 RLLM2060
 RLLM2070
 RLLM2080
 RLLM2090
 RLLM2100
 RLLM2110
 RLLM2120
 RLLM2130
 RLLM2140
 RLLM2150
 RLLM2160
 RLLM2170
 RLLM2180
 RLLM2190
 RLLM2200
 RLLM2210
 RLLM2220
 RLLM2230
 RLLM2240
 RLLM2250
 RLLM2260
 RLLM2270
 RLLM2280
 RLLM2290
 RLLM2300
 RLLM2310
 RLLM2320
 RLLM2330
 RLLM2340
 RLLM2350
 RLLM2360
 RLLM2370
 RLLM2380
 RLLM2390
 RLLM2400
 RLLM2410
 RLLM2420
 RLLM2430
 RLLM2440
 RLLM2450
 RLLM2460
 RLLM2470
 RLLM2480
 RLLM2490
 RLLM2500
 RLLM2510
 RLLM2520


```

C 205 DO 210 J=1,N
      XY(IPCCL,IPROW) = CNE/PIVOT
      D = WK(IPROW)
      WK(IPRCW) = XY(IFCOL,MP3)
      XY(IPCCL,MP3) = D
      ITER = ITER+1
      GO TO (70,130,145), LEV

C 210 CONTINUE
      XY(J,MP5) = ZERO
      IF (MCDE.EQ.2) GC TO 240
      DO 215 J=1,IRANK
        K = XY(J,MP3)
        BETA(K) = XY(J,MP2)
      215 CONTINUE
      IF (MCDE.EQ.3.OR.IRANK.EQ.N) GO TO 240
      DO 220 I=MP1R,MF1
        K = ABS(WK(I))-FMM
        XY(K,MP5) = XY(N,MP2)*SIGN(CNE,WK(I))
      220 CONTINUE
      IF (IRANK1.EQ.N) GO TO 230
      DO 225 J=IRANK1,NM1
        K = ABS(XY(J,MP3))-FMM
        XY(K,MP5) = {XY(N,MP2)-XY(J,MP2)}*SIGN(ONE,XY(J,MP3))
      225 CONTINUE

C 230 DO 235 I=MP1R,MF1
      IF (ABS(XY(N,I)).GT.TOL) GO TO 235
      IER = 33
      GC TO 240

235 CONTINUE
      IF (MCDE.NE.2.ANC.MODE.NE.3) REMAX = XY(N,MP2)
      IF (IRANK.EQ.N) REMAX = ZERO
      IF (MCDE.EQ.4) REMAX = REMAX-D
      IF (IER.EQ.C) GO TO 9005
9000 CONTINUE
      CALL UERTST (IER,6HRLMV )
9005 RETURN
      END
SUBROUTINE GGNML (DSEED,NR,R)

```

SPECIFICATIONS FOR ARGUMENTS

```

C  C
C  INTEGER NR
C  REAL R(NR)
C  DOUBLE PRECISION USED

```

SPECIFICATIONS FOR LOCAL VARIABLES

FIRST EXECUTABLE STATEMENT

RLLM3010
RLLM3020
RLLM3030
RLLM3040
RLLM3050
RLLM3060
RLLM3070
RLLM3080
RLLM3090
RLLM3100
RLLM3110
RLLM3120
RLLM3130
RLLM3140
RLLM3150
RLLM3160
RLLM3170
RLLM3180
RLLM3190
RLLM3200
RLLM3210
RLLM3220
RLLM3230
RLLM3240
RLLM3250
RLLM3260
RLLM3270
RLLM3280
RLLM3290
RLLM3300
RLLM3310
RLLM3320
RLLM3330
RLLM3340
RLLM3350
RLLM3360
RLLM3370
RLLM3380
GGNH0380
GGNH0390
GGNH0400
GGNH0410
GGNH0420
GGNH0430
GGNH0440
GGNH0450
GGNH0460


```

C      CALL GGUBS([SEEC,NR,R)
C      GET NR RANDOM NUMBERS
C      TRANSFORMS EACH UNIFORM DEVIATE

DO 5 I=1,NR
  CALL MDNRIS(R(I),R(I),IER)
5 CONTINUE
  RETURN
END
SUBROUTINE LERTST (IER,NAME)
  INTEGER IER
  INTEGER*2 NAME(3)
  INTEGER*2
  INTEGER*2
  DATA
  DATA
  DATA
  IF (IER.GT.999) GO TO 25
  IF (IER.LT.-32) GO TO 55
  IF (IER.LE.128) GO TO 5
  IF (LEVEL.LT.1) GO TO 30
  CALL UGETIO(1,NIN,IOUNTIT)
  IF (IEQDF.EC.1) WRITE(IOUNTIT,35) IER,NAMEQ,IEQ,NAME
  IF (IEQDF.EC.0) WRITE(IOUNTIT,35) IER,NAME
  GO TO 30
5 IF (IER.LE.64) GO TO 10
  IF (LEVEL.LT.2) GO TO 30
  CALL UGETIO(1,NIN,IOUNTIT)
  IF (IEQDF.EC.1) WRITE(IOUNTIT,40) IER,NAMEQ,IEQ,NAME
  IF (IEQDF.EC.0) WRITE(IOUNTIT,40) IER,NAME
  GO TO 30
10 IF (IER.LE.32) GO TO 15
  IF (LEVEL.LT.3) GO TO 30
  CALL UGETIO(1,NIN,IOUNTIT)
  IF (IEQDF.EC.1) WRITE(IOUNTIT,45) IER,NAMEQ,IEQ,NAME
  IF (IEQDF.EC.0) WRITE(IOUNTIT,45) IER,NAME
  GO TO 30
15 CONTINUE
  CHECK FOR UERSET CALL
DO 20 I=1,3
  IF (NAME(I).NE.NAMSET(I)) GO TO 25
20 CONTINUE
  LEVELOLD = LEVEL
  LEVEL = IER

```

```

GGNH0470
GGNH0480
GGNH0490
GGNH0500
GGNH0510
GGNH0520
GGNH0530
GGNH0540
UERT0500
UERT0510
UERT0520
UERT0530
UERT0540
UERT0550
UERT0560
UERT0570
UERT0580
UERT0590
UERT0600
UERT0610
UERT0620
UERT0630
UERT0640
UERT0650
UERT0660
UERT0670
UERT0680
UERT0690
UERT0700
UERT0710
UERT0720
UERT0730
UERT0740
UERT0750
UERT0760
UERT0770
UERT0780
UERT0790
UERT0800
UERT0810
UERT0820
UERT0830
UERT0840
UERT0850
UERT0860
UERT0870
UERT0880
UERT0890

```



```

IER = LEVOLD
IF (LEVEL.LT.0) LEVEL = 4
IF (LEVEL.GT.4) LEVEL = 4
GO TO 30
25 CONTINUE
IF (LEVEL.LT.4) GO TO 30
C
CALL UGETIO(1,NIN,IOUNIT)
IF (IECDF.EQ.1) WRITE(IOUNIT,50) IER,NAMEQ,IEQ,NAME
IF (IECDF.EQ.0) WRITE(IOUNIT,50) IER,NAME
30 IEQDF = 0
RETURN
35 FORMAT(19H ** TERMINAL ERROR,10X,7H( IER = ,I3,
1 20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
40 FORMAT(36H ** WARNING WITH FIX ERROR, ( IER = ,I3,
1 20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
45 FORMAT(18H ** WARNING ERROR,11X,7H( IER = ,I3,
1 20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
50 FORMAT(20H ** UNDEFINED ERROR,9X,7H( IER = ,I5,
1 20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
SAVE P FOR P = R CASE
P IS THE PAGE NAME
R IS THE ROUTINE NAME
C
55 IEQDF = 1
DO 60 I=1,3
60 NAMEQ(I) = NAME(I)
65 RETURN
END
SUBROUTINE UGETIC(IOPT,NIN,NOUT)
C
C SPECIFICATIONS FOR ARGUMENTS
C IOPT,NIN,NOUT
C
C SPECIFICATIONS FOR LOCAL VARIABLES
C
C FIRST EXECUTABLE STATEMENT
C
IF (IOPT.EQ.3) GO TO 10
IF (IOPT.EQ.2) GO TO 5
IF (ICPT.NE.1) GO TO 9005
NIN = NIND
NOUT = NOUTC
GO TO 9005
5 NIND = NIN
GO TO 9005
10 NOUTD = NOUT
9005 RETURN
END
SUBROUTINE GGUBS (DSEED,NR,R)
C SPECIFICATIONS FOR ARGUMENTS

```

UERT0900
 UERT0910
 UERT0920
 UERT0930
 UERT0940
 UERT0950
 UERT0960
 UERT0970
 UERT0980
 UERT0990
 UERT1000
 UERT1010
 UERT1020
 UERT1030
 UERT1040
 UERT1050
 UERT1060
 UERT1070
 UERT1080
 UERT1090
 UERT1100
 UERT1110
 UERT1120
 UERT1130
 UERT1140
 UERT1150
 UERT1160
 UERT1170
 UGET0480
 UGET0490
 UGET0500
 UGET0510
 UGET0520
 UGET0530
 UGET0540
 UGET0550
 UGET0560
 UGET0570
 UGET0580
 UGET0590
 UGET0600
 UGET0610
 UGET0620
 UGET0630
 UGET0640
 UGET0650
 GGUS0390
 GGUS0400


```

SD = ((WI+H2)*WI+H1)*WI+HO
Y = W + W*(GO+SN/SD)
Y = -Y*SQRT2
GO TO 9005
9000 CONTINUE
CALL UERTST(IER,6HMDNRIS)
9005 RETURN
END
SUBROUTINE MERFI (P,Y,IER)
C
REAL P,Y
INTEGER IER
C
** *
REAL A,B,X,Z,W,WI,SN,SD,F,Z2,RINFM,A1,A2,A3,B0,B1,
B2,B3,C0,C1,C2,C3,D0,D1,D2,E0,E1,E2,E3,F0,F1,
F2,G0,G1,G2,G3,HC,H1,H2,SIGMA
DATA A1/-5751703//,A2/-1.896513//,A3/-5496261E-1/
DATA B0/-1137730//,B1/-3.293474//,B2/-2.374996/
DATA B3/-1.187515/
DATA C0/-1146666//,C1/-1314774//,C2/-2368201/
DATA C3/.5073975E-1/
DATA D0/-44.27977//,D1/21.98546//,D2/-7.586103/
DATA E0/-5668422E-1//,E1/.3937021//,E2/-3166501/
DATA E3/.6208963E-1/
DATA F0/-6.266786//,F1/4.666263//,F2/-2.962883/
DATA G0/.1851159E-3//,G1/-2028152E-2/
DATA G2/-1498384//,G3/.1078639E-1/
DATA H0/.9952975E-1//,H1/.5211733/
DATA H2/-6888301E-1/
DATA RINFM/27FFFFF/
FIRST EXECUTABLE STATEMENT
C
IER = 0
X = P
SIGMA = SIGN(1.0,X)
C
IF (.NOT.(X.GT.-1. .AND. X.LT.1.)) GO TO 30
Z = ABS(X)
IF (Z.LE. .85) GC TO 20
A = 1.-Z
B = Z
C
5 W = SCRT(-ALCG(A+A*B))
IF (W.LT.2.5) GC TO 15
IF (W.LT.4.) GO TO 10
C
WI = 1./W
C
REDUCED ARGUMENT IS IN (.85,1.),
OBTAIN THE TRANSFORMED VARIABLE
W GREATER THAN 4., APPROX. F BY A
RATIONAL FUNCTION IN 1./W

```

MCRS0730
MCRS0740
MCRS0750
MCRS0760
MCRS0770
MCRS0780
MCRS0790
MCRS0800
MERI0390
MERI0400
MERI0410
MERI0420
MERI0430
MERI0440
MERI0450
MERI0460
MERI0470
MERI0480
MERI0490
MERI0500
MERI0510
MERI0520
MERI0530
MERI0540
MERI0550
MERI0560
MERI0570
MERI0580
MERI0590
MERI0600
MERI0610
MERI0620
MERI0630
MERI0640
MERI0650
MERI0660
MERI0670
MERI0680
MERI0690
MERI0700
MERI0710
MERI0720
MERI0730
MERI0740
MERI0750
MERI0760
MERI0770
MERI0780


```

      SN = ((G3*W1+G2)*W1+G1)*W1
      SD = ((W1+H2)*W1+H1)*W1+H0
      F = W + W*(GC+SN/SD)
      GO TO 25

C
C
      10  SN = ((E3*W+E2)*W+E1)*W
      SD = ((W+F2)*W+F1)*W+F0
      F = W + W*(EC+SN/SD)
      GO TO 25

C
C
      15  SN = ((C3*W+C2)*W+C1)*W
      SD = ((W+D2)*W+D1)*W+D0
      F = W + W*(CO+SN/SD)
      GO TO 25

C
C
      20  Z2 = Z*Z
      F = Z+Z*(B0+A1*Z2/(B1+Z2+A2/(B2+Z2+A3/(B3+Z2))))
      FCRM THE SOLUTION BY MULT. F BY
      THE PROPER SIGN

C
C
      25  Y = SIGMA*F
      IER = 0
      GO TO 9005

C
C
      30  IER = 129
      Y = SIGMA * RINFM
      9000 CONTINUE
      CALL UERTST(IER,6HMERFI )
      9005 RETURN
      END

```

W BETWEEN 2.5 AND 4., APPROX. F
BY A RATIONAL FUNCTION IN W

W BETWEEN 1.13222 AND 2.5, APPROX.
F BY A RATIONAL FUNCTION IN W

Z BETWEEN 0. AND .85, APPRCX. F
BY A RATIONAL FUNCTION IN Z
FCRM THE SOLUTION BY MULT. F BY
THE PROPER SIGN

ERROR EXIT. SET SOLUTION TO PLUS
(OR MINUS) INFINITY

MER110790
MERR10800
MERR10810
MERR10820
MERR10830
MERR10840
MERR10850
MERR10860
MERR10870
MERR10880
MERR10890
MERR10900
MERR10910
MERR10920
MERR10930
MERR10940
MERR10950
MERR10960
MERR10970
MERR10980
MERR10990
MERR11000
MERR11010
MERR11020
MERR11030
MERR11040
MERR11050
MERR11060
MERR11070
MERR11080
MERR11090
MERR11100
MERR11110

UUUUUUUU

69


```

40 C(I,J)=B(I,J)/(B(I,J)+B(J,I))
41 GO TO 41
C(I,J)=C.50
CONTINUE
200 WRITE(6,200) (C(I,J),J=1,K)
FORMAT(12X,5(F6.2,2X))
42 CONTINUE
203 WRITE(6,203)
FORMAT(//,1X,'Z(I,J) MATRIX')
DO 52 I=1,K
DO 51 J=1,K
IF (C(I,J).GT.0.98.OR.C(I,J).LT.0.02) GO TO 50
CALL MDNRIS(C(I,J),Z(I,J),IER)
GO TO 51
Z(I,J)=1000.
CONTINUE
50 WRITE(6,200) (Z(I,J),J=1,K)
51 CONTINUE
52 WRITE(6,204)
FORMAT(//,16X,'OBJECTIVE FUNCTION COEFFICIENTS')
204 WRITE(6,205)
FORMAT(//,15X,'-----',///)
205 WRITE(6,206)
FORMAT(5X,'TANKS',6X,'AMTRACKS',5X,'RADIOS',6X,'TRUCKS',
*5X,'HOWITZERS')
206 WRITE(6,207)
FORMAT(//,15X,'-----',5X,'-----',6X,'-----',
*5X,'-----',7)
DO 63 I=1,K
DO 61 MN(I)=0
IF (Z(I,J).EQ.1000.) GO TO 60
SZ(I)=SZ(I)+Z(I,J)
GO TO 61
MN(I)=2
WRITE(6,220) I
FORMAT(5X,'ROW',I4,' NCT COMPLETE')
60 CONTINUE
220 IF (MN(I).GT.1) GO TO 63
SZ(I)=SZ(I)/K
61 CONTINUE
63 DO 88 I=1,K
SZ(I)=SZ(I)+1.1520
88 CONTINUE
WRITE(6,225) SZ(1),SZ(2),SZ(3),SZ(4),SZ(5)
225 FORMAT(1X,5(F10.4,2X))
RETURN
END

```



```
C      SUBROUTINE MCNRIS (P,Y,IER)
C
C      REAL
C      INTEGER
C
C      P,Y
C      IER
C
C      EPS,G0,G1,G2,G3,H0,H1,H2,A,W,WI,SN,SD
C      SIGMA,SQR12,X,XINF
C      XINF/Z7FFFFF/XINF
C      SQR12/1.414214/
C      EPS/Z3C1000C0/
C      G0/.1851159E-3/,G1/-2028152E-2/
C      G2/--.1498384/,G3/.1078639E-1/
C      HC/.9952975E-1/,H1/.5211733/
C      H2/--.6888301E-1/
C
C      FIRST EXECUTABLE STATEMENT
C
C      IER = 0
C      IF (P .GT. C.O .AND. P .LT. 1.0) GO TO 5
C      IER = 129
C      SIGMA = SIGN(1.0,P)
C      Y = SIGMA * XINF
C      GO TO 9000
C
C      5 IF(P.LE.EPS) GO TO 10
C      X=1.0-(P+P)
C      CALL MERFI(X,Y,IER)
C      Y=-SQR12 * Y
C      GO TO 9005
C
C      10 A = P+P
C      W = SQRT(-ALCG(A+(A-A*A)))
C
C      WI = 1./W
C      SN = ((G3*WI+G2)*WI+G1)*WI
C      SD = ((WI+H2)*WI+H1)*WI+HO
C      Y = W + W*(GO+SN/SD)
C      Y = -Y*SQR12
C      GO TO 9005
C
C      9000 CONTINUE
C      CALL UERTST(IER,6HMDNRIS)
C      RETURN
C      END
C
C      SUBROUTINE MERFI (P,Y,IER)
C
C      REAL
C      INTEGER
C
C      P,Y
C      IER
C
C      A,B,X,Z,W,WI,SN,SD,F,Z2,RINFM,A1,A2,A3,B0,B1,
C      B2,B3,C0,C1,C2,C3,D0,D1,C2,E0,E1,E2,E3,FC,FL,
C      F2,G0,G1,G2,G3,H0,H1,H2,SIGMA
C
C      SPECIFICATIONS FOR ARGUMENTS
C
C      SPECIFICATIONS FOR LOCAL VARIABLES
```



```

DATA      A1/-0.5751703/,A2/-1.896513/,A3/-0.5496261E-1/
DATA      B0/-0.1137730/,B1/-3.293474/,B2/-2.374996/
DATA      B3/-1.187515/
DATA      C0/-0.1146666/,C1/-0.1314774/,C2/-0.2368201/
DATA      C3/-0.5073975E-1/
DATA      D0/-0.4.27977/,D1/21.98546/,D2/-7.586103/
DATA      E0/-0.5668422E-1/,E1/.3937021/,E2/-0.3166501/
DATA      E3/-0.6208963E-1/
DATA      F0/-6.266786/,F1/4.666263/,F2/-2.962883/
DATA      G0/-1.851159E-3/,G1/-0.2028152E-2/
DATA      G2/-0.1498384/,G3/.1078639E-1/
DATA      H0/.9952975E-1/,H1/.5211733/
DATA      H2/-0.6888301E-1/
DATA      RINFM/27FFFFF/
C          IER = 0
C          X = P
C          SIGMA = SIGN(1.0,X)
C          IF (.NOT.(X.GT.-1. .AND. X.LT.1.)) GO TO 30
C          Z = ABS(X)
C          IF (Z.LE. .85) GO TO 20
C          A = 1.-Z
C          B = Z
C          W = SQRT(-ALCG(A+A*B))
C          IF (W.LT.2.5) GO TO 15
C          IF (W.LT.4.) GO TO 10
C          WI = 1./W
C          SN = ((G3*WI+G2)*WI+G1)*WI
C          SD = ((WI+H2)*WI+H1)*WI+H0
C          F = W + W*(G0+SN/SD)
C          GO TO 25
C          10 SN = ((E3*W+E2)*W+E1)*W
C          SD = ((W+F2)*W+F1)*W+F0
C          F = W + W*(E0+SN/SD)
C          GO TO 25
C          15 SN = ((C3*W+C2)*W+C1)*W
C          SD = ((W+D2)*W+D1)*W+D0
C          F = W + W*(C0+SN/SD)
C          GO TO 25
C          FIRST EXECUTABLE STATEMENT
C          TEST FOR INVALID ARGUMENT
C          X.LT.1.)) GO TO 30
C          REDUCED ARGUMENT IS IN (.85,1.),
C          OBTAIN THE TRANSFORMED VARIABLE
C          W GREATER THAN 4., APPROX. F BY A
C          RATIONAL FUNCTION IN 1./W
C          W BETWEEN 2.5 AND 4., APPROX. F
C          BY A RATIONAL FUNCTION IN W
C          W BETWEEN 1.13222 AND 2.5, APPROX.
C          F BY A RATIONAL FUNCTION IN W

```

```

MERI0470
MERI0480
MERI0490
MERI0500
MERI0510
MERI0520
MERI0530
MERI0540
MERI0550
MERI0560
MERI0570
MERI0580
MERI0590
MERI0600
MERI0610
MERI0620
MERI0630
MERI0640
MERI0650
MERI0660
MERI0670
MERI0680
MERI0690
MERI0700
MERI0710
MERI0720
MERI0730
MERI0740
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MERI0780
MERI0790
MERI0800
MERI0810
MERI0820
MERI0830
MERI0840
MERI0850
MERI0860
MERI0870
MERI0880
MERI0890
MERI0900
MERI0910
MERI0920
MERI0930
MERI0940

```



```

C      Z BETWEEN C. AND .85, APPRCX. F
C      BY A RATIONAL FUNCTION IN Z
2C  Z2 = Z*Z
F = Z+Z*(B0+A1*Z2/(B1+Z2+A2/(B2+Z2+A3/(B3+Z2))))
C      FCRM THE SOLUTION BY MULT. F BY
C      THE PROPER SIGN
25  Y = SIGMA*F
IER = 0
GO TO 9005

C      ERROR EXIT. SET SOLUTION TO PLUS
C      (OR MINUS) INFINITY
30  IER = 129
Y = SIGMA * RINFM
9000 CONTINUE
9005 CALL UERTST(IER,6HMERFI )
      RETURN
      END
SUBROUTINE UERTST (IER,NAME)
C
C      SPECIFICATIONS FOR ARGUMENTS
C      INTEGER IER
C      CHARACTER NAME(3)
C      INTEGER*2 NAMEQ(3)
C      DATA NAMEQ/2HUE,2HRS,2HET/
C      DATA NAMEQ/2H ,2H ,2H /
C      DATA LEVEL/4/,IEQDF/0/,IEQ/1H=/
IF (IER.GT.999) GO TO 25
IF (IER.LT.-32) GO TO 55
IF (IER.LE.128) GO TO 5
IF (LEVEL.LT.1) GO TO 30
CALL UGETIO(1,NIN,IOUNIT)
IF (IEQDF.EC.1) WRITE(IOUNIT,35) IER,NAMEQ,IEQ,NAME
IF (IEQDF.EC.0) WRITE(IOUNIT,35) IER,NAME
GO TO 30
5  IF (IER.LE.64) GC TO 10
IF (LEVEL.LT.2) GO TO 30
CALL UGETIO(1,NIN,IOUNIT)
IF (IEQDF.EC.1) WRITE(IOUNIT,40) IER,NAMEQ,IEQ,NAME
IF (IEQDF.EC.0) WRITE(IOUNIT,40) IER,NAME
GO TO 30
10 IF (IER.LE.32) GC TO 15
IF (LEVEL.LT.3) GO TO 30
CALL UGETIO(1,NIN,IOUNIT)
IF (IEQDF.EC.1) WRITE(IOUNIT,45) IER,NAMEQ,IEQ,NAME

```

```

MER10950
MER10960
MER10970
MER10980
MER10990
MER11000
MER11010
MER11020
MER11030
MER11040
MER11050
MER11060
MER11070
MER11080
MER11090
MER11100
MER11110
UERT0500
UERT0510
UERT0520
UERT0530
UERT0540
UERT0550
UERT0560
UERT0570
UERT0580
UERT0590
UERT0600
UERT0610
UERT0620
UERT0630
UERT0640
UERT0650
UERT0660
UERT0670
UERT0680
UERT0690
UERT0700
UERT0710
UERT0720
UERT0730
UERT0740
UERT0750
UERT0760
UERT0770
UERT0780
UERT0790
UERT0800

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LERT0810
 UERT0820
 UERT0830
 UERT0840
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 UERT0990
 UERT1000
 UERT1010
 UERT1020
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 UERT1080
 UERT1090
 UERT1100
 UERT1110
 UERT1120
 UERT1130
 UERT1140
 UERT1150
 UERT1160
 UERT1170
 UGET0480
 UGET0490
 UGET0500
 UGET0510
 UGET0520
 UGET0530
 UGET0540
 UGET0550
 UGET0560
 UGET0570
 UGET0580

```

    IF (IEQDF.EC.0) WRITE(IOUNT,45) IER,NAME
    GO TO 30
  15 CONTINUE
      CHECK FOR UERSET CALL
      DO 20 I=1,3
      IF (NAME(I).NE.NAMSET(I)) GC TO 25
  20 CONTINUE
      LEVEL = IER
      LEVEL = LEVCLD
      IER = LEVEL
      IF (LEVEL.LT.0) LEVEL = 4
      IF (LEVEL.GT.4) LEVEL = 4
      GO TO 30
  25 CONTINUE
      IF (LEVEL.LT.4) GO TO 30
      PRINT NON-DEFINED MESSAGE
      CALL UGETIO(1,NIN,IOUNT)
      IF (IEQDF.EC.1) WRITE(IOUNT,50) IER,NAMEQ,IEQ,NAME
      IF (IEQDF.EC.0) WRITE(IOUNT,50) IER,NAME
  30 IEQDF = 0
      RETURN
  35 FORMAT(19H ** TERMINAL ERROR,10X,7H( IER = ,I3,
    20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
  40 FORMAT(36H ** WARNING WITH FIX ERROR' ( IER = ,I3,
    20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
  45 FORMAT(18H ** WARNING ERROR,11X,7H( IER = ,I3,
    20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
  50 FORMAT(20H ** UNDEFINED ERROR,9X,7H( IER = ,I5,
    20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
    SAVE P FOR P = R CASE
    P IS THE PAGE NAME
    R IS THE ROUTINE NAME
  55 IEQDF = 1
  60 NAMEC(I) = NAME(I)
  65 RETURN
      END
      SUBROUTINE UGETIC(IOPT,NIN,NOUT)
      SPECIFICATIONS FOR ARGUMENTS
      INTEGER ICPT,NIN,NOUT
      SPECIFICATIONS FOR LOCAL VARIABLES
      INTEGER NIND,NOUTD
      DATA NIND/5/,NOUTD/6/
      FIRST EXECUTABLE STATEMENT
      IF (IOPT.EQ.3) GC TO 10
      IF (ICPT.EQ.2) GC TO 5
      IF (IOPT.NE.1) GC TO 9C05
      NIN = NIND
  
```



```

NOUT = NCUTC
GO TO 9005
5 NIND = NIN
GO TO 9005
10 NOUTD = NOUT
9005 RETURN
END

```

```

UGEI0590
UGEI0600
UGEI0610
UGEI0620
UGEI0630
UGEI0640
UGEI0650

```


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